GEOPHYSICAL IP/RESISTIVITY SURVEY

Pima County Harrison Landfill

Tucson, Arizona

Final Report

for

The City of Tucson

Environmental Services

ZONGE JOB# 13089

Issue Date: August 15, 2013

Zonge International, Inc.
3322 E. Fort Lowell Rd.
Tucson. Arizona, USA 85716
Zonge@zonge.com *www.zonge.com*

Figures and Tables

(Large scale, high resolution versions of all figures are included as separate files on the report CD.)

Geophysical IP/Resistivity Surveys

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EXECUTIVE SUMMARY

On July 10th, 11th, and 12th, 2013, Zonge International, Inc. conducted a geophysical induced polarization (IP) and resistivity survey for The City of Tucson (COT), Environmental Services on the Pima County Harrison Landfill project in Tucson, Arizona. The goal of the survey was to map subsurface features that may be related to an anomalous methane reading in a monitor well (called HAH83) in the Harrison Hills Mobile Home Park. Mr. Richard Byrd was the primary contact during the survey, and Tim Nordstrom was the Zonge field crew chief. The general site location is shown below in Figure 1.

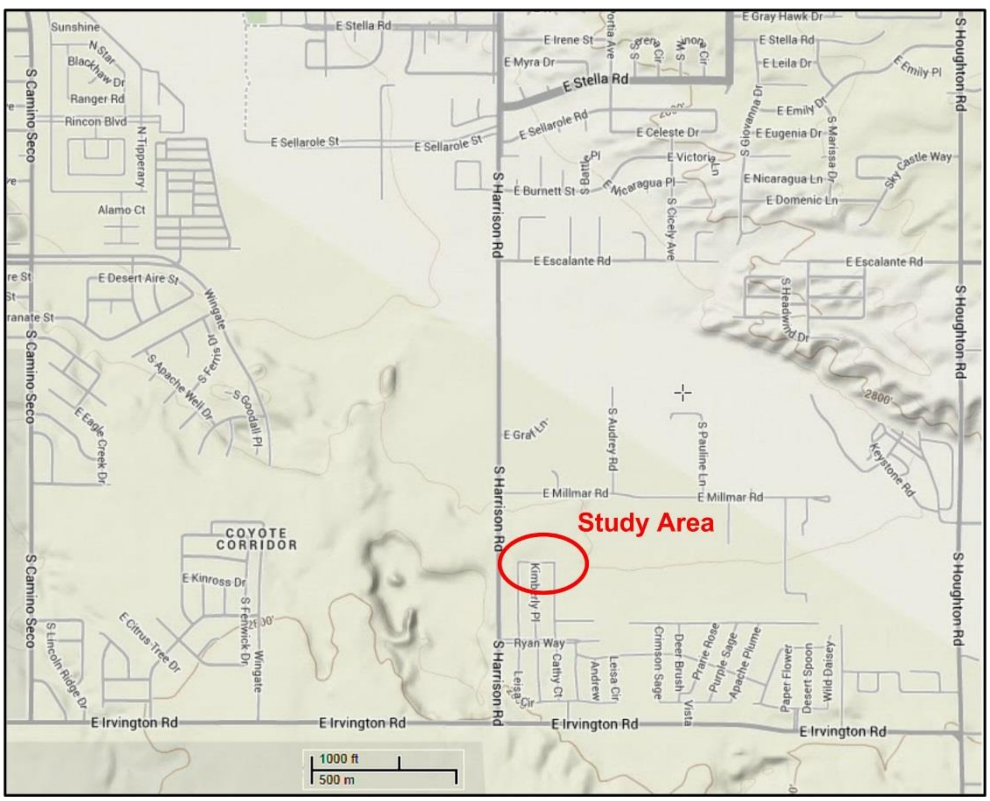

Figure 1: Pima County Harrison Landfill survey location.

Data were acquired on five lines as shown in Figure 2, with stations spaced every 7.5 feet along the lines. Line 1 was an east-west line across the landfill to determine the electrical properties of the buried waste at this site. Line 2 was south of Line 1, also east-west, but in between the landfill and the mobile home park. Line 3 was within the mobile home park, located along the northern edge of Terryann Circle, approximately 50 feet north of monitor well HAH83, and Line 4 was approximately 50 feet south of the well, running between mobile homes and crossing the north-south road Kimberly Place. Line 5 was roughly north-south, and was added to the survey to better understand the results of Lines 1 and 2.

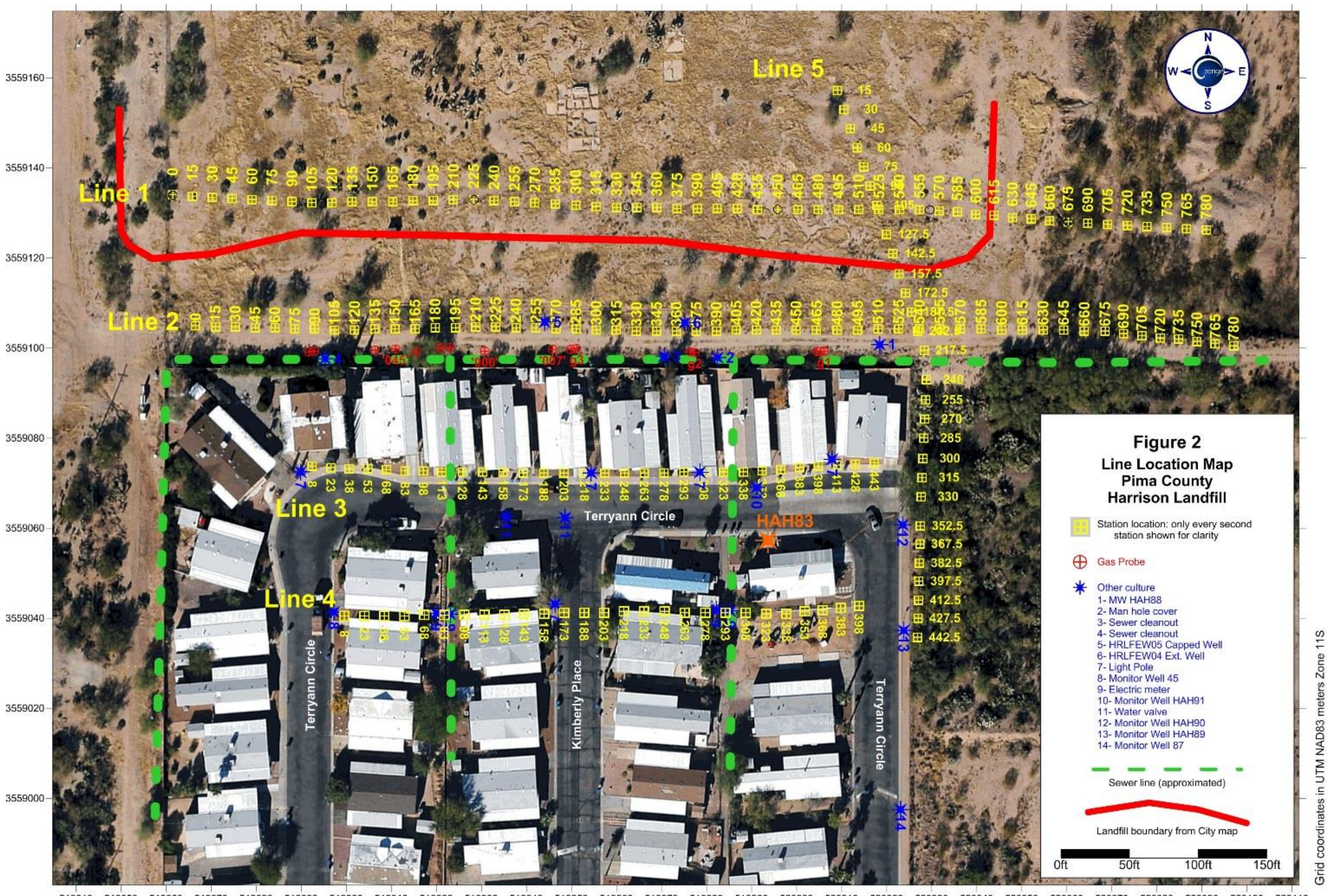

Figure 2: Geophysical survey line locations on the Pima County Harrison Landfill Project.

Numerous past geophysical surveys have shown that buried waste, including municipal solid waste (MSW), construction waste, and in some cases, green waste, cause elevated IP values when compared to background areas which do not contain waste. Using the IP results in conjunction with the resistivity results can also often assist with the interpretation of the types of waste material suspected below grade. The survey results at this site are summarized in Figures 3 and 4. High IP values are seen along Line 1, which is typical of results seen over most landfills; the extent of the high IP values are in very good agreement with the mapped limit of the landfill based on information provided by COT. A particularly strong pocket of high IP values is seen from station 458 to 623, suggesting a denser volume of waste, or more metallic waste in that area. Moderately high IP values are also seen on Line 2, suggesting that buried waste is very close to or beneath Line 2. The vast majority of the data on these two northern lines are very clean and repeatable.

Lines 3 and 4 were within the mobile home park, and therefore more likely to be adversely affected by nearby electrical noise (from utilities, for example) and cultural features (man-made conductive features such as metal pipelines, fences, and structures). Cultural features had very little effect on Line 3, and the results along most of the line were moderately low IP values, suggesting little or no waste, with the exception of a moderately strong IP response centered beneath station 368, approximately 50 feet north of monitor well HAH83. This anomaly is very similar to the anomalous values associated with known waste on Lines 1 and 5 in both IP and resistivity, but this location is also very close to a concrete drainage that is assumed to have metallic rebar, which could also cause an IP response. Though it is unlikely there is waste beneath the rest of Line 3, it is possible, though not certain, that there is a pocket of waste (municipal solid waste (MSW), or green waste) beneath station 368, from approximately station 360 to 380. The elevated IP response would tend to exclude construction waste, based on comparison to prior results at other landfills in the southwestern US.

Line 4 showed several very strong IP anomalies, but there are obvious cultural effects on this line from utilities, as well as gaps in the data crossing Kimberly Place. Data were noisy, unrepeatable, and showed unrealistic values of IP and resistivity. Very strong IP anomalies beneath stations 75, 135, 180, 210, 285, and from station 330 to the end of the line are all interpreted to be the result of cultural noise. It is possible that one or more of these cultural anomalies are masking a valid waste anomaly, however, so it is not possible to determine with certainty whether or not Line 4 crossed any pockets of waste.

Line 5 verified the strong IP anomaly associated with waste on Line 1 and the moderate IP values on Line 2. Noisy data were evident when this line crossed the concrete drainage (which extends in to the vacant land east of the mobile home park).

In summary, Lines 1, 2, and 5 verified that the waste at this site can be delineated with the IP survey, and that the southern boundary of the waste may be further south than shown on the map provided by COT, which shows waste boundary taken from maps generated by Pima County and Pima Association of Governments. Based on these results, there appears to be a subsurface structure (pit or trench) containing waste (MSW, or green waste) beneath station 368 on Line 3, approximately 50 feet north of monitor well HAH83, but this is not a certainty due to the close proximity of a concrete drainage structure. It is not likely that there is buried waste under the remainder of Line 3. Line 4 was strongly affected by cultural features, and it is not possible to conclusively determine whether or not waste is present under Line 4.

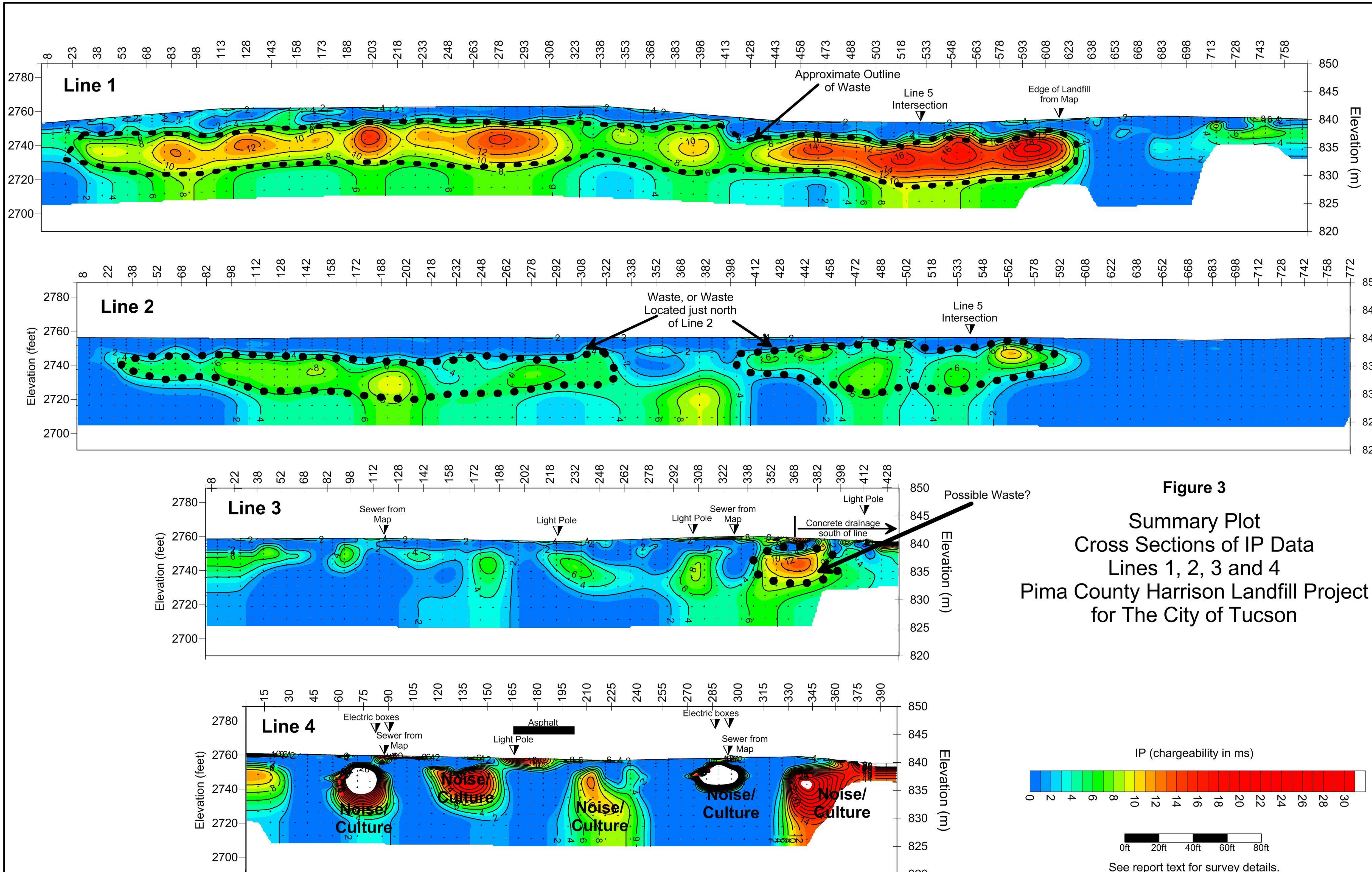

Figure 3

Summary Plot
Cross Sections of IP Data
Lines 1, 2, 3 and 4
Pima County Harrison Landfill Project
for The City of Tucson

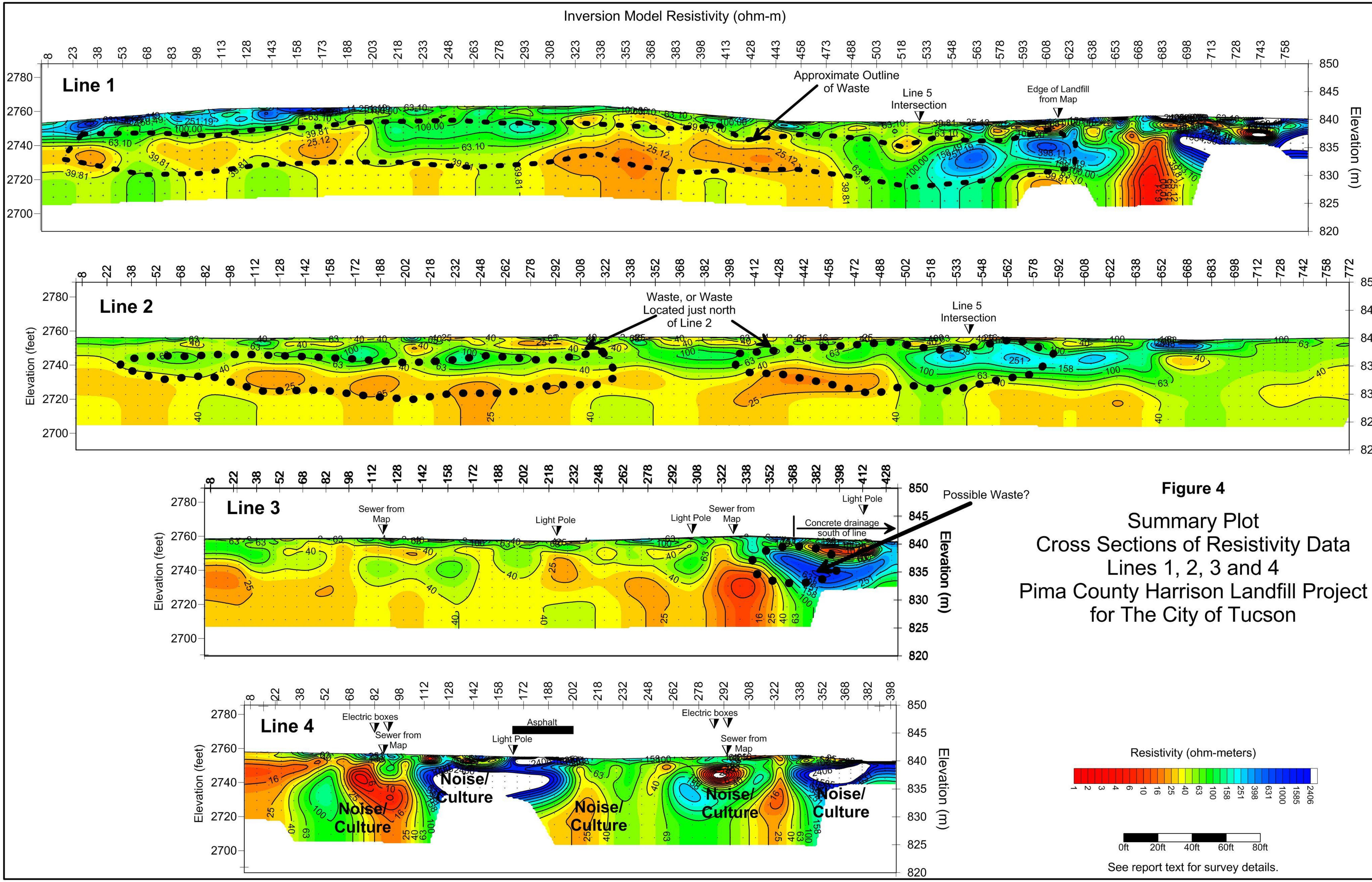

Figure 4

Summary Plot
Cross Sections of Resistivity Data
Lines 1, 2, 3 and 4
Pima County Harrison Landfill Project
for The City of Tucson

LOGISTICAL INFORMATION

Survey Production- Logistically, the survey progressed smoothly, with no significant delays due to either weather or equipment problems. Table 1 below summarizes the crew activities on a day-by-day basis.

TABLE 1: LOGISTICAL SUMMARY

Date	Production Summary for 13089	Production Hrs.	# Crew
07-10-2013	Data acquisition on Line 1 (partial) and Line 2.	11	4
07-11-2013	Data acquisition on Lines 3 and 4; finish Line 1.	7.50	4
07-12-2013	Data acquisition on Line 5.	5.50	4

Field Instrumentation- All data were acquired with a Zonge model GDP-32II multiple purpose receiver (SN 3244-252). The Zonge GDP-32II instrument is a backpack-portable, 16 bit, microprocessor-controlled receiver that can gather data on as many as 16 channels simultaneously, and was used in conjunction with a Zonge MX-30 multiplexer. The transmitter used for this survey was a Zonge ZT-30 transmitter. Detailed equipment specifications are included as Appendix B for reference.

Data were acquired in the time domain, using a 0.5 Hz repetition rate, 50% duty cycle, square wave signal with resistivity values calculated from peak voltage during the on-times, and decay amplitudes were measured in 13 windows during the off-times. IP as chargeability is effectively the integration of the data from 125 milliseconds to 275 milliseconds after turn-off (roughly windows 4, 5, 6, and 7). Eight complete cycles are stacked and averaged in order to average out random noise, and these eight cycles constitute one measurement or data block; all data blocks are repeated at least once to establish repeatability, and in the array used on this project, at least two diagonals of data (out of each spread of 15) are overlapped and repeated to verify equipment operation after each move.

Line Locations- Lines were established in the field by the crew using hand-held GPS, based on suggestions by COT. Line statistics are shown in Table 2 below; coordinates are in UTM NAD83 (meters), Zone 12S.

TABLE 2: IP/RESISTIVITY SURVEY LINE STATISTICS

Line #	Starting Point		Ending Point		Dipole spacing (ft)	# of stations	Line Length (ft)
	Easting	Northing	Easting	Northing			
1	519861	3559134	520093	3559126	15	102	761
2	519867	3559105	520099	3559100	15	104	761
3	519890	3559074	520019	3559075	15	58	423
4	519897	3559041	520009	3559042	15	53	367
5	520008	3559162	520027	3559034	15	58	425

Cultural Features- Cultural features include man-made electrically conductive objects such as metal fences, power lines, pipelines, and buried utilities that may distort the measurements. Cultural features also include active noise sources that radiate electromagnetic signals, such as radio and TV transmitters, active power lines, and pipelines with cathodic protection. No cultural features were crossed on Lines 1 and 2, though Line 2 was located in close proximity to a sewer line, and to Pima County's vapor extraction system (which is operating along the southern edge of the landfill). Lines 3 and 4 were within the mobile home park, and numerous cultural features were noted by the field crew, including landfill gas monitoring wells, electrical utility boxes, manhole covers, and light poles. There are also likely to be cultural features that were not evident at the surface to the crew. Cultural effects on the data are discussed below in the line-by-line discussion.

Data Quality- One quantitative measure of data quality is repeatability between measurements at the same data point, as well as between measurements of overlapping data points between equipment set-up spreads. Appendix D includes plots showing data repeatability for both IP and resistivity, with data points shown at their plot point in traditional pseudosection format. For IP, the posted value is the standard error of the mean (SEM), which is the standard deviation divided by the square root of the number of cycles in the stack. For the vast majority of the datapoints on this survey, the SEMs are very small (less than 1ms), indicating very clean, repeatable data. Noisy datapoints are seen as multiple, disparate values (from the multiple stacks of data) overlaid at the noisy datapoint. For the resistivity data, the percentage error in the resistivity measurement repeats is shown. (Note that in cases of very noisy values, the percentage error is shown simply as 999.) As in the case of IP, the vast majority of the datapoints show very small percentage errors, indicating clean, repeatable data.

It is important to note, however, that coherent noise or distortions in the received signal from cultural features can be repetitive, thus even though data measurements may be repeatable, it may not be a valid response of subsurface features. Recognition of invalid but repeatable data is part of the interpretation process, and involves examination of measurement amplitudes, comparison to prior project results, and comparison of the raw data to calculated data in the modeling process.

Smooth Model Inversion Modeling- Smooth-model inversion is a robust method for converting resistivity and IP measurements to smoothly varying model cross-sections. In the TS2DIP program, observed apparent resistivities are averaged to initialize a background resistivity model while background-model IP values are set to one. Interactive tools allow background model editing to include known geology. Resistivity and IP values in the two-dimensional model section are then iteratively modified until calculated data values match observed data as closely as possible, subject to constraints on model smoothness and the difference between background and inverted model values.

Constraints control the character of TS2DIP's inversion models. Separate constraint parameters are included for vertical smoothness, horizontal smoothness and for difference from an arbitrary background model. Constraint weighting can be varied to suit geologic conditions. Increasing the weighting of vertical smoothness constraints is appropriate in areas with steeply dipping geology, while increasing horizontal smoothness-constraint weighting is more suitable for flat lying geology. Constraining model parameter values to stay close to a background model is useful for incorporating independent geologic information in the inversion.

The finite-element forward-modeling algorithm used in TS2DIP v4.70e calculates apparent resistivity and phase values generated by two-dimensional models to an accuracy of about 5 percent. When topographic profile information is included during model setup, TS2DIP's finite-element mesh is draped over the terrain.

LINE-BY-LINE DISCUSSION

Results of processing and modeling the data are shown in Figures 3, 4, and 7 as cross sections of IP and resistivity, with station numbers (in feet from the start of the line) across the top of the cross sections and elevation down the side (in feet on the left side, and in meters on the right side). IP cross sections for all lines use the same contour and color scale, with linear contours and shading of elevated IP values in milliradians toward the red end of the spectrum, and near-zero, background values shaded toward blue. Resistivity sections are contoured logarithmically in ohm-meters, and shaded with low values toward red, and high values toward blue.

Appendix C includes the reference data plots for each line. Each of the Appendix C plots show 3 images for each line. The top image in each plot is the final model result (either IP or resistivity) as described above in cross section form. This plot is at a 1:1 scale, i.e., no vertical exaggeration. The bottom and middle images are the raw (labeled “observed”) and calculated data in traditional pseudosection format, with station numbers across the top and increasing n-spacing down the side. Comparison of the observed and calculated (bottom and middle) plots is informative with respect to data quality and multi-dimensional effects. Very noisy, unrealistic data or 3D, off-line effects often cause poor agreement between the observed and calculated pseudosections. For Lines 1 and 2, the agreement is good in both the resistivity and IP data sets, suggesting good quality data, and that off-line, 3D effects are not likely to be a problem. Differences between the observed and calculated images for Lines 3, 4, and 5 are evident, and primarily the result of cultural noise.

Figures 5 and 6 are 3D perspective plots showing all the IP cross sections as viewed from the southwest (Figure 5) and from the northeast (Figure 6), in order to more easily visualize the relationships and locations of the subsurface IP anomalies. Color shading is similar to other data plots, but not identical due to the difference in plotting programs; elevated IP values are shaded toward the red end of the spectrum, and near-zero, background IP values are shaded toward blue. The vertical scale has been exaggerated 2:1 in order to aid visibility in the perspective view. Several key surface features have been added for reference, such as the fence which surrounds the mobile home park, and the outline of asphalt roads.

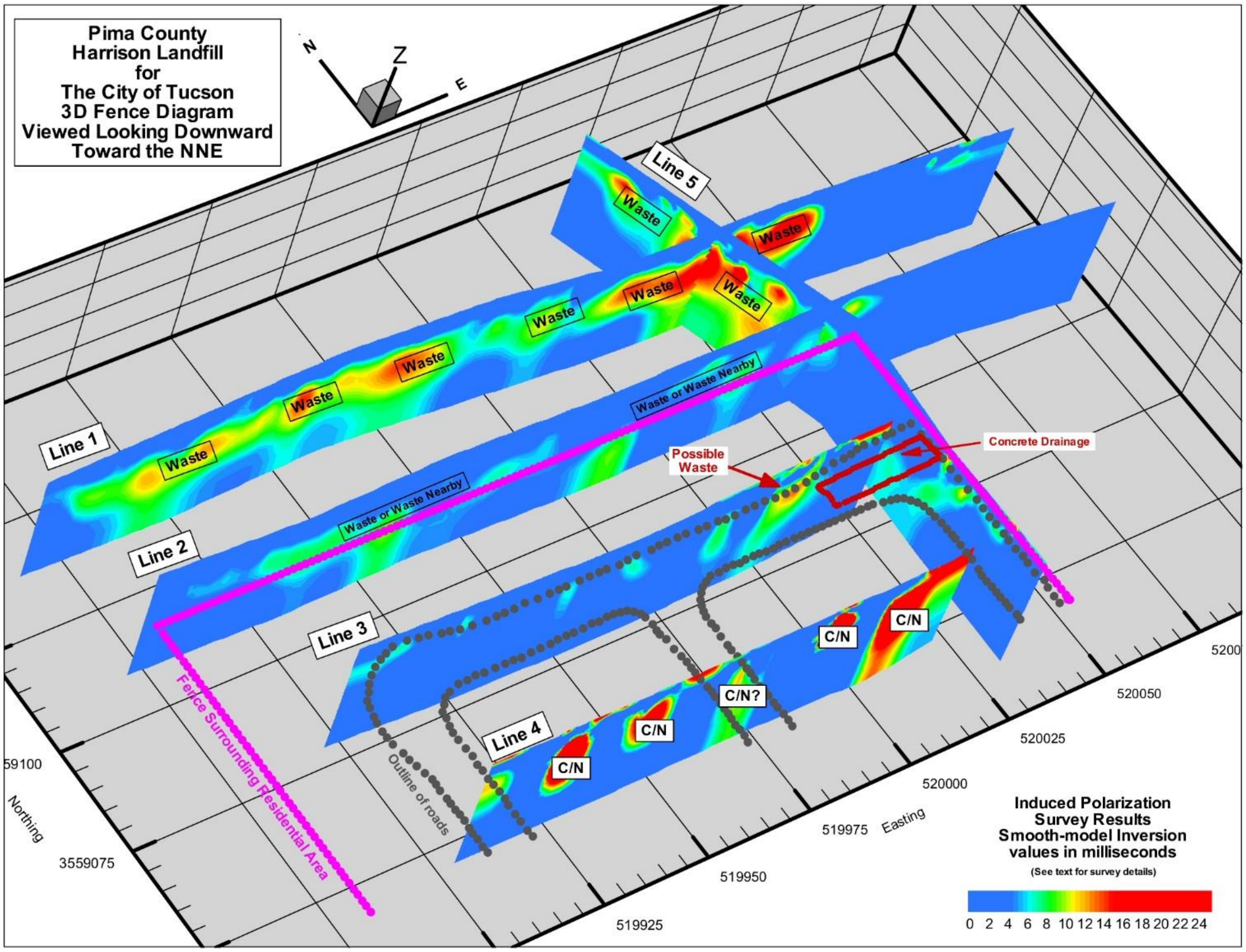

Figure 5: IP cross sections as a fence diagram in 3D perspective, viewed from the southwest. Areas labeled "C/N" are interpreted to be anomalies resulting from cultural features or noise.

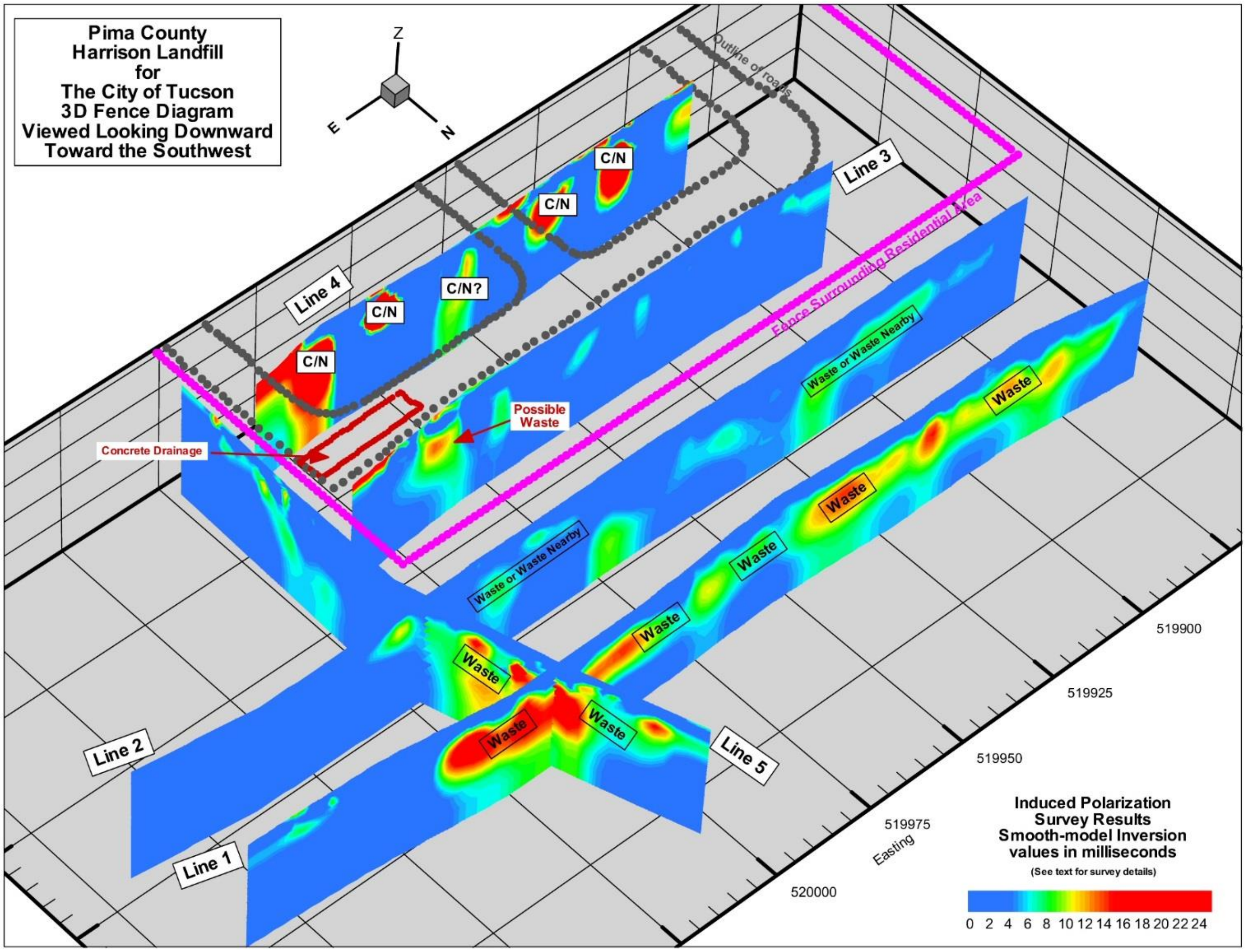

Figure 6: IP cross sections as a fence diagram in 3D perspective, viewed from the northeast. Areas labeled "C/N" are interpreted to be anomalies resulting from cultural features or noise.

Line 1- Line 1 was oriented east-west, was the northernmost line, and extended from near the west edge of the landfill to approximately 200 feet beyond the landfill on the east. This line was intended to determine the electrical characteristics of the subsurface waste (municipal solid waste (MSW), construction waste, and green waste) at this site, as well as to establish that background areas with no waste were distinguishable from the areas of known waste. Data quality along this line was good, with good repeatability at most points, and good agreement between the observed and calculated results. The far eastern end of the line was somewhat noisy in IP, apparently from poor contact resistance.

The IP results for Line 1 (see Figure 3) show well-defined high IP values associated with the extent of the buried waste along this line, based on approximate outline of waste provided by COT. East of the landfill, from approximately station 623 to the east end of the line, IP values drop to near-zero, background levels, as expected for an area where there is no waste in the subsurface. The high IP values do not extend to the surface, and it appears there may be as much as 5 to 10 feet of cover over the waste in some parts of this landfill. The deepest data along the line do show decreasing IP values, suggesting that the waste is not extremely thick at this site. There are no boreholes to calibrate the base of the waste in the model, but from a general comparison to other data sets, the waste is probably no thicker than 20 feet at most locations along this line.

Within this large IP anomaly are two zones where the IP values are very strong, suggesting more dense waste (MSW, or green waste), or possibly waste containing more metal than other parts of the landfill. The zone from station 458 to approximately station 610 has very high IP values, and this zone also is higher in resistivity (Figure 4) than other parts of the landfill. Additionally, from station 203 to 300 both IP and resistivity values are higher than other parts of the landfill also indicative of MSW or green waste.

Line 2- Line 2 was located approximately 90 feet south of Line 1, between the landfill and the mobile home park. This line did not cross any obvious cultural features, and the data on Line 2 were very clean and repeatable. According to maps on the Pima County GIS web site, a sewer line runs parallel and very close to this entire line, but no adverse effects are seen in the data. It is possible that the sewer line is only approximately located on the GIS maps, and that Line 2 is actually 15 to 20 feet north of the sewer line.

The results for this line exhibit an IP anomaly very similar in extent to Line 1, but noticeably weaker. Based on the approximate southern limit of the landfill shown on the COT map, this line is 50 to 65 feet south of the waste, thus IP effects from the waste were not expected on this line. The elevated IP effects on this line most likely indicate that the actual southern limit of waste is closer to this line than shown on the COT map. It is interesting to note that the strongest zones of the IP anomaly on Line 1 correlate very closely to the strongest zones on Line 2, both data sets suggesting a weakening of the anomaly near the center of the lines (from station 323 to 443 on Line 1, and from 330 to 400 on Line 2). In addition, moderately higher resistivities are seen on the east end of the IP anomaly on Line 2, similar to the high resistivities seen on the east end of the IP anomaly on Line 1.

Line 3- Line 3 was located along the northern edge of the east-west section of Terryann Circle. This location is one of the few straight-line stretches where electrodes could be planted in soil without the need to drill holes through the asphalt road. Although this line is very close to mobile homes and a sidewalk, the data are relatively clean and realistic, and in generally good agreement with the background IP and resistivity levels seen on Lines 1 and 2. IP levels west of station 338 on this line are low, suggesting little or no waste, though this area is not as clean and near-zero as the east end of Line 2. The very weak anomalies that are seen west of station

338 are interpreted to be the result of cultural noise, including weak features beneath stations 98, 180, 232, and 308.

Moderately high IP values are seen from approximately station 360 to 380. Though some of the data in this area are definitely noisy, some of these moderately high values appear valid, and it is possible that the line crosses a buried pocket or trench of waste (MSW, or green waste). It is interesting to note that this area also exhibits high resistivities, which makes it similar to the east end of the high IP anomaly associated with waste on Line 1. From station 368 to the east end of the line, a concrete drainage slab parallels the line approximately 15 to 20 feet to the south. Assuming this slab contains metal reinforcement either as rebar or mesh, this could be the source of the noisy data at this end of the line, and it may be contributing to the elevated IP values.

The resistivity data (Figure 4) for this line indicate resistivities lower than normal for this site beneath station 330, which is coincident with one of the two north-south sewer lines that cross this line and Line 4. Even though these low resistivities are shown fairly deep, it is not uncommon for cultural features to be poorly modeled and to appear deeper and larger than their actual nature. The western sewer (which intersects this line at station 120) does not appear as a low resistivity anomaly, however, suggesting that either there is something anomalous about the eastern sewer, or there is a low resistivity anomaly (such as a buried trench or disturbed soil, for example) in the vicinity of the eastern sewer.

Line 4- Line 4 was an east-west line located approximately 50 feet south of monitor well HAH83, running between mobile homes; electrodes on the asphalt crossing Kimberly Place were too high in contact resistance to acquire valid data, resulting in poor data quality in that area. This line crossed the same two north-south sewers that were crossed by Line 3, and the crew also noted four electrical utility boxes very close to the line as shown on the line location map (Figure 2). It is likely this line crossed additional buried cultural features that the crew did not observe.

Some of the data on this line are noisy, and unrealistically high or low in IP or resistivity. In particular, very anomalous IP values are seen beneath stations 75, 135, 180, 210, 285, and from station 330 to the east end of the line. Due to the poor repeatability or unusual decay curve characteristics, these are all interpreted to be the result of noise and culture. Given these strong effects, it is not possible to definitively determine whether or not Line 4 crossed any subsurface waste, since these cultural effects may be masking an IP anomaly from buried waste.

Line 5- Line 5 was a cross line added to the survey program after examining Lines 1 and 2, in order to verify the results of those lines. Line 5 was approximately north-south, intersecting Line 1 in the vicinity of high IP values at station 525, and Line 2 in moderate IP values at station 540. The Line 5 IP results (Figure 7 below) are in good agreement with Lines 1 and 2, verifying that the southern limit of the subsurface waste is likely to be much closer to Line 2 than expected. South of station 240, this line was very close to and parallel to a metal fence, which likely influenced the data. Low resistivities from station 232 to 292 may be the result of the fence, while very high resistivities that begin at station 322 and extend to the south are likely the result of the concrete drainage centered at station 330, which created very high contact resistance on the electrodes.

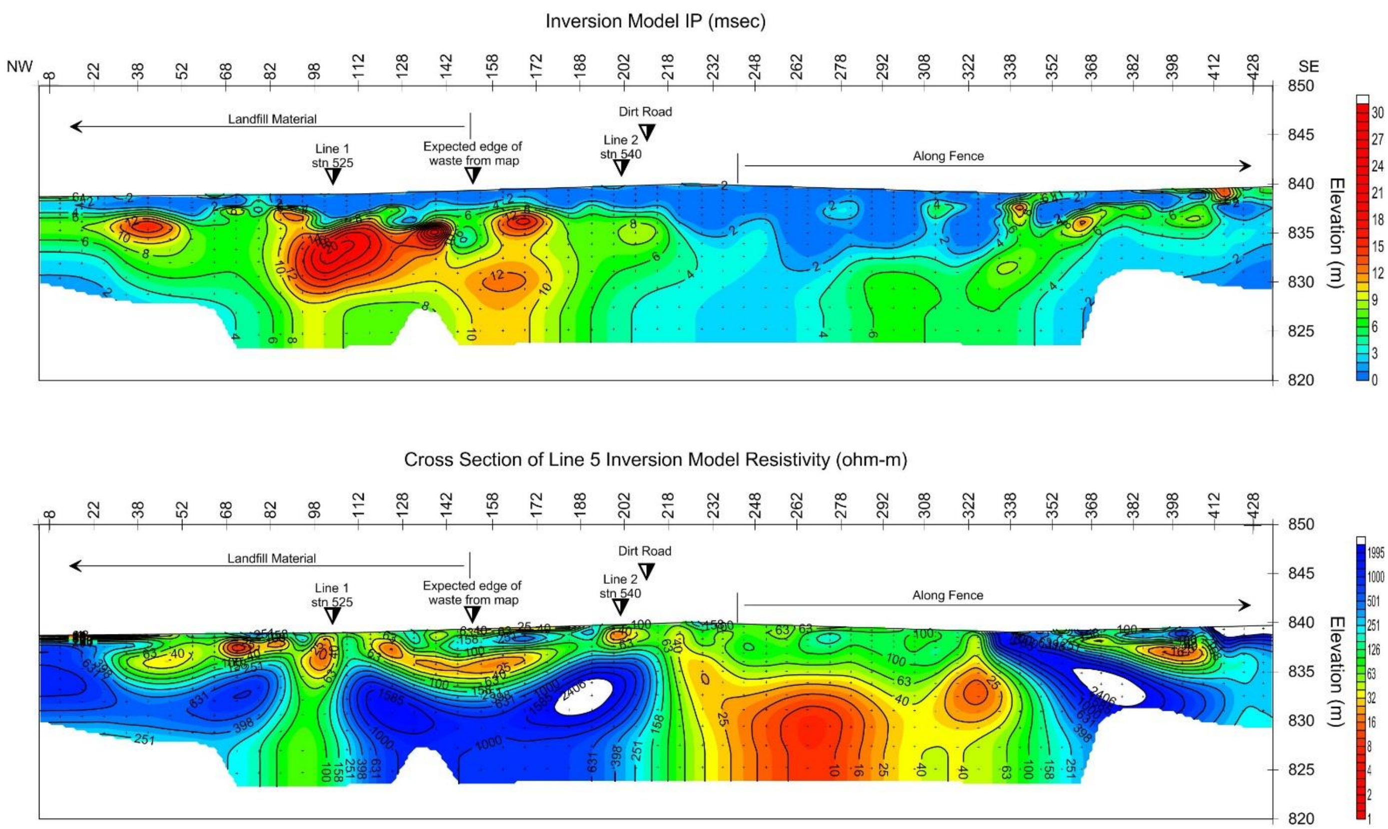

Figure 7: Cross sections of IP (top) and resistivity (bottom) for the cross line 5.

SUGGESTIONS FOR FURTHER WORK

The geophysical survey at the Pima County Harrison Landfill determined that the subsurface waste at the site is detectable using an IP and resistivity survey, but an IP anomaly beneath Line 3 within the mobile home park has not been definitively determined to be waste because of cultural noise effects. Other geophysical techniques have been considered in an effort to verify this anomaly, but the site conditions and depth preclude most other methods. For example, a magnetic survey would be useful only if the waste is known to contain ferrous metals, and if cultural noise does not interfere with the measurements. It is not likely that ground penetrating radar (GPR) would have the necessary depth of investigation in these low resistivity soils, and a seismic survey could detect disturbed soil, but it is not likely to delineate waste from disturbed soils. If additional IP lines are considered, it would be necessary to use electrodes in the asphalt roadway, which would require drilling ¾ inch diameter holes in the asphalt in order to make good electrical contact with the soil beneath. This technique has been used successfully at other sites around Tucson, but it is inherently more intrusive than the current survey.

Respectfully submitted,

Norman Carlson

Chief Geophysicist
Zonge International, Inc.
3322 E. Fort Lowell Road
Tucson, AZ 85716
USA
Phone: 520-327-5501 FAX: 520-325-1588

norman.carlson@zonge.com

APPENDIX A

References Regarding IP/Resistivity Applications to Landfill Delineation

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GEOPHYSICAL IP/RESISTIVITY SURVEY

Pima County Harrison Landfill

Tucson, Arizona

Appendix B

Equipment Specifications

for

The City of Tucson

Environmental Services

ZONGE JOB# 13089

Issue Date: August 15, 2013

Zonge International, Inc.
3322 E. Fort Lowell Rd.
Tucson. Arizona, USA 85716

GDP-32^{II} Geophysical Receiver
Multi-Function Receiver

The GDP-32^{II} is Zonge Engineering's fourth generation multi-channel receiver for acquisition of controlled- and natural-source geoelectric and EM data.

ENHANCEMENTS

- **66 or 133 MHz 586 processor**
- **Expanded keyboard**
- **½-VGA graphics display**
- **Ethernet port**
- **Full Windows 95® compatibility**

UNIQUE CAPABILITIES

- **Remote control operation**
- **Broadband time-series recording**
- **High-speed data transfer**

FEATURES

- 1 to 16 channels, user expandable
- Alphanumeric keypad
- 66 or 133 MHz 586 CPU
- Easy to use menu-driven software
- Resistivity, Time/Frequency Domain IP, CR, CSAMT, Harmonic analysis CSAMT (HACSAMT), AMT, MT, TEM & NanoTEM®
- Screen graphics: plots of time-domain decay, resistivity and phase, complex plane plots, etc., on a 480x320 ½-VGA, sunlight readable LCD
- Internal humidity and temperature sensors
- Time schedule program for remote operation with the XMT-32S transmitter controller
- Use as a data logger for analog data, borehole data, etc.
- Full compatibility with GDP-16 and GDP-32 series receivers.
- 0.015625 Hz to 8 KHz frequency range standard, 0.0007 Hz minimum for MT
- One 16-bit A/D per channel for maximum speed and phase accuracy.
- 256 Mb flash RAM (up to 1 Gb) for program and data storage, sufficient to hold many days worth of data.
- 16 Mb dRAM (up to 48 Mb) for program execution.
- 4 Gb hard disk (up to 40 Gb) for time series data storage.
- Real-time data and statistics display
- Anti-alias, powerline notch, and telluric filtering
- Automatic SP buckout, gain setting, and calibration
- Rugged, portable, and environmentally sealed
- Modular design for upgrades and board replacement
- Complete support: field peripherals, service network, software, and training

Zonge Engineering and Research Organization, Inc.
Specialists in Electrical Geophysics • Field Surveys • Geophysical Consulting • Instrumentation Sales and Lease

SPECIFICATIONS FOR THE GDP-32^{II} MULTI-FUNCTION RECEIVER

General

Broadband, multichannel, multifunction digital receiver.
Frequency range: 1/64Hz - 8KHz (0.0007Hz - 8KHz for MT)
Number of channels: Large case, 1 to 16 (user expandable)
Small case, 1 to 6 (user expandable).
Standard Survey capabilities: Resistivity, Frequency- and Time-Domain IP, Complex Resistivity, CSAMT (scalar, vector, tensor), Harmonic Analysis (CSAMT, Frequency-Domain EM, Transient Electromagnetics, NanoTEM®, MMR, Magnetic IP, Magnetotellurics, Downhole Logging.
Software language: C++ and assembly.
Size: Large case 43x41x23cm (17x16x9")
Small case 43x31x23cm (17x12x9")
Weight: (including batteries and meter/connection panel):
Small case 13.7 kg (29 lb)
Large case:
8 channel, 10 amp-hr batteries, 16.6 kg (36.5 lb)
8 channel, 20 amp-hr batteries, 20.5 kg (45 lb)
16 channel, disk, 10 amp-hr batteries, 19.1 kg (42 lb)
Enclosure: Heavy-duty, environmentally sealed aluminum
Power: 12V rechargeable batteries (removable pack)
Over 10 hours nominal operation at 20°C (8 channels and 20 amp-hr batteries). External battery input for extended operation in cold climates, or for more than 8 channels.
Temperature range: -40° to +45°C (-40° to +115°F)
Humidity range: 5% to 100%
Internal temperature and humidity sensors
Time base: Oven-controlled crystal oscillator; aging rate <$5x10^{-10}$ per 24 hours (GPS disciplining optional)

Displays & Controls

High-contrast sunlight readable ½-VGA (480x320) DFT-technology LCD graphics display, with continuous view-angle adjustment (optional heater for use down to –40°C).
Sealed 80-key keyboard
Analog signal meters and analog outputs
Power On-Off

Standard Analog

Input impedance: 10 MΩ at DC
Dynamic range: 190 db
Minimum detectable signal: 0.03 μV
Maximum input voltage: ±32V
SP offset adjustment: ±2.25V in 69μV steps (automatic)
Automatic gain ranging in binary steps from 1/8 to 65,536
Common-mode rejection at 1000 Hz: >80 db
Phase accuracy: ±0.1 milliradians (0.006 degree)
Adjacent channel isolation at 100 Hz: >90 db
Filter Section: Four-pole Bessel anti-alias filter (software-controlled) Quadruple-notch digital telluric filter (50/150/250/450 Hz, 50/150/60/180 Hz, 60/180/300/540 Hz, specified by user)
Analog to Digital Converter (Standard Channel)
Resolution: 16 bits ± ½ LSB
Conversion time: 17 μsec
Continuous self calibration
One A/D per channel for maximum speed and phase accuracy

NanoTEM® Analog

Input impedance: 20 KΩ at DC
Dynamic range: 120 db
Minimum detectable signal: 4 μV
Automatic gain ranging in binary steps from 10 to 160
Analog to Digital Converter: 14 bits ± ½ LSB, 16 bits optional
Conversion time: 1.2 μsec
One A/D per channel for maximum data acquisition speed

Digital Section

Microprocessor: 66 MHz 586 (133 MHz optional)
Memory: 16 Mb dRAM (up to 48 Mb)
Mass Storage (program & data storage):
256 Mb flash RAM (up to 1 Gb).
Hard disk drives with capacities to 40 Gb optional
Serial ports: 2 RS-232C ports (16650) standard
Parallel port: 1 SPP and EPP compatible printer port
Network Adapter: Ethernet adapter standard (10Base-T)
Mouse, CRT (VGA), and standard keyboard ports
Standard Operating System: Windows 95®

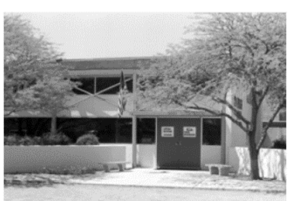
Additional Options

Number of channels: (maximum of 3 NanoTEM® channels)
Large case: 1-16, Small case: 1-6
External battery and LCD heater for –40°C operation

Other Acquisition Software

***External RPIP/TDIP/CR Control**:* Remote control through serial port on GDP-32^{II} for electrical resistance tomography (ERT).
***Streaming RPIP/TDIP**:* Continuous acquisition of TDIP or RPIP data (time domain or resistivity/phase IP) using a towed electrode array.
***Borehole TEM**:* Remote control through GDP-32^{II} serial port for efficient logging of borehole TEM and MMR data. Compatible with Crone and Geonics 3-component probes.
***Extended Broadband Time Series Data Recording**:* Continuous recording of up to 5 standard analog channels sampling at 32 K samples/sec (bandwidth 8 KHz with 2x oversampling) with no loss of data. The recording time is limited only by the size of the hard disk drive. Developed for recording broadband magnetotelluric measurements.
***Equal-Interval Mode TEM (TEME)**:* Uniform sampling and storage of TEM transients as time series. Used for LOTEM data acquisition and any application that requires uniformly sampled TEM transients.

Specifications subject to change without notice



Zonge Engineering and Research Organization, Inc.
Offices:
Arizona, Alaska, Nevada, Australia and Chile
Headquarters:
3322 E. Ft. Lowell Road, Tucson, AZ 85716, USA (800) 523-9913
Tel: (520) 327-5501 Email: zonge@zonge.com
Fax: (520) 325-1588 Web: http://www.zonge.com

20031024

ZT-30 TRANSMITTER

Battery-Powered EM / Resistivity Transmitter

DESCRIPTION

The ZT-30 is a battery-powered transmitter capable of producing time-domain or frequency-domain waveforms into either resistive or inductive loads. As a TEM transmitter, the ZT-30 can deliver up to 30A into a 100m loop with a turnoff time of less than 200 μs. Because the ZT-30 also performs well while transmitting into resistive loads, some customers are using it as a low-power resistivity transmitter. When used for resistivity, it is necessary to monitor the current since the transmitter does not have current regulation circuitry.

FEATURES

- Bipolar current output up to 30 A
- 50 or 100% duty cycle
- 1 microsecond turnoff into resistive load
- Less than 150 microseconds turnoff into a 100 meter loop at 20 amperes
- Lightweight, battery powered

Zonge Engineering and Research Organization, Inc.
Specialists in Electrical Geophysics • Field Surveys • Geophysical Consulting • Instrumentation Sales and Lease

SPECIFICATIONS FOR THE ZT-30 TEM TRANSMITTER

Mechanical
Case size: 45 x 18 x 28 cm
(17.7 x 7.1 x 11.0 in)
Weight: 8 kg (17.6 lb) *(without batteries)*

Electrical
Input voltage: 14 to 136 Vdc (400 Vdc selectable)
Peak output current: 30 A unregulated
Transmit control by GDP receiver or XMT-series
Transmitter controller
(DC ≤ f ≤ 32 Hz TD, DC ≤ f ≤ 512 Hz FD)
Isolated current monitor output
Automatic overcurrent shutdown (set for 33 A)
IGBT power output current switch
Power contactor to remove voltage from
transmitter during fault conditions
Lamps to indicate state of transmitter:
power on, transmitting, fault, polarity
Fan-cooled heatsink

Controls & Displays
Power on / off
Transmit / Reset
Damping Select
Meter Select
LCD Displays:
Input voltage
Internal battery voltage
Output current
Turnoff time
Heat sink temperature

Fault Indicators
Over / Under Voltage
Over Current
Over Temperature

Output Jacks
Current monitor terminals, isolated output
50 mV/A or 1 V/A ranges
Output current terminals

Power
Internal battery: 10.9 to 14V, Logic Power
Main Power connector: four-pin military twist-lock,
14 – 400 Vdc

Applications
TEM transmitter, 136 Vdc max @ 30 amps
Low current transmitter for TD & FD Resistivity/IP,
400 Vdc max @ 7 amps

Options
ZPB-600 400 Vdc Power Booster

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Tel: (520) 327-5501 Email: zonge@zonge.com
Fax: (520) 325-1588 Web: http://www.zonge.com

THE MX-30

Multiplex Switch

DESCRIPTION

The MX-30 was developed to provide a computer-controlled switching interface between a transmitter, a multi-channel receiver such as the GDP-32^{II}, and an array of electrodes. The MX-30 features a transmitter input multiplexer which can connect the transmitter leads to any pair of electrodes. A receiver multiplexer permits the operator to select any number of electrode pairs (up to half the number of electrodes) for input to the receiver. Multiplexer configuration is controlled by commands transmitted over an RS-232C serial communications channel. A control program is available for a laptop computer. The MX-30 is an essential component of any system designed to rapidly acquire resistivity data using cabled electrode arrays. Customers are currently using the MX-30 together with a GDP-32^{II} receiver and a ZT-30 transmitter to gather data for **Electrical Resistivity Tomography**. The MX-30 can be configured to provide fewer channels at a reduced cost. The unit can be upgraded in the field at a later date to give it increased output channel capacity.

FEATURES

- Selectable Electrode String – 30 electrodes Max
- External Control – RS-232C Serial (4800,N,8,1)
- Signal Output Channels (differential) – 16 Max
- Transmitter Output Relay Specs - ±500 Vdc 5 A
- Transmitter/Receiver Channel Isolation – 1000V
- High Speed Optical Relays on Receiver MUX
- Fully compatible with GDP-32^{II} Receiver
- MX-30's may be cascaded together to address several electrode arrays

Zonge Engineering and Research Organization, Inc.

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GEOPHYSICAL IP/RESISTIVITY SURVEY

Pima County Harrison Landfill

Tucson, Arizona

Appendix C

Reference Data Plots

for

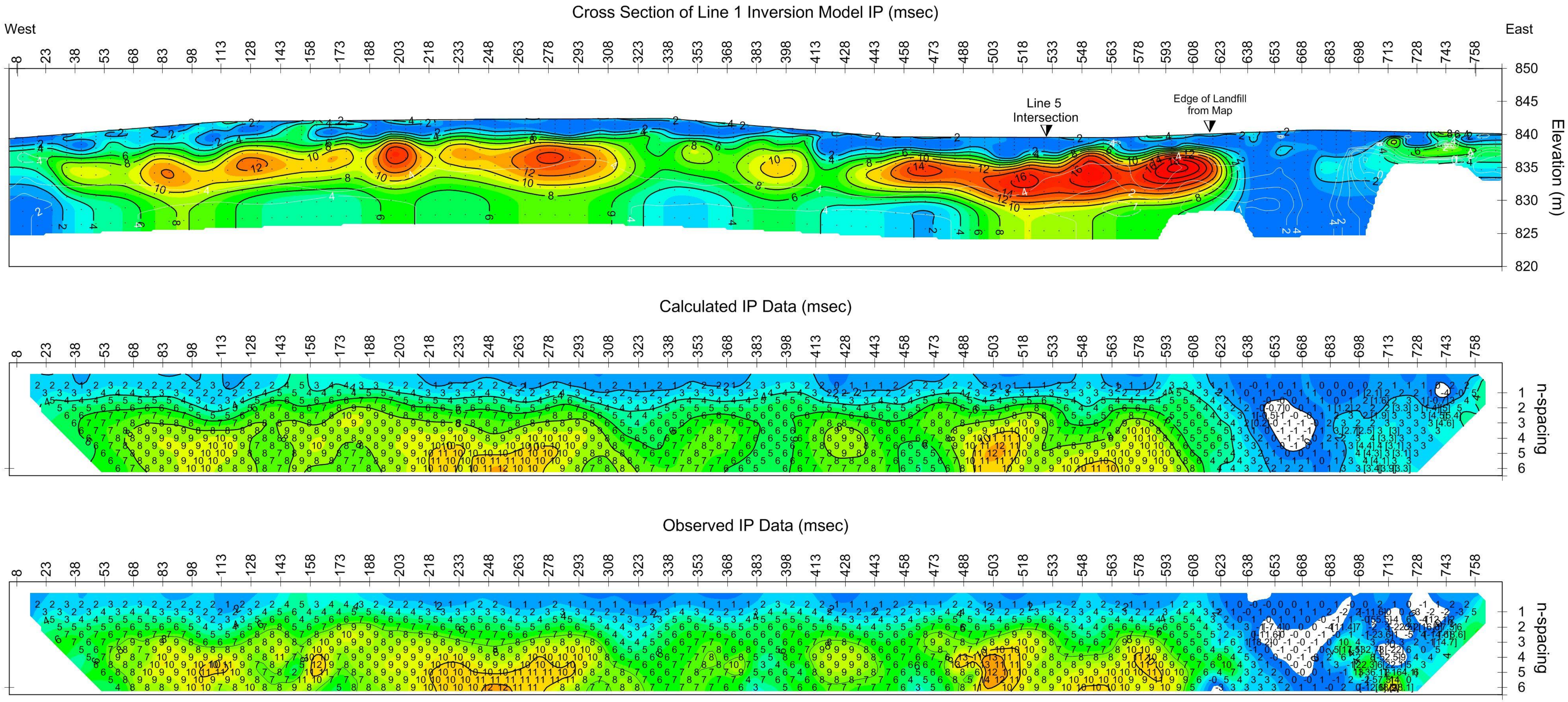
The City of Tucson

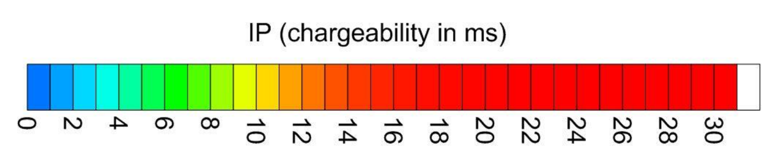
Environmental Services

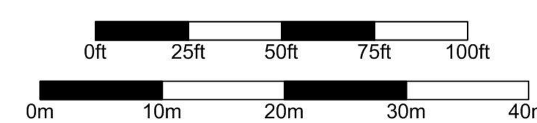
ZONGE JOB# 13089

Issue Date: August 15, 2013

Zonge International, Inc.
3322 E. Fort Lowell Rd.
Tucson. Arizona, USA 85716
Zonge@zonge.com *www.zonge.com*





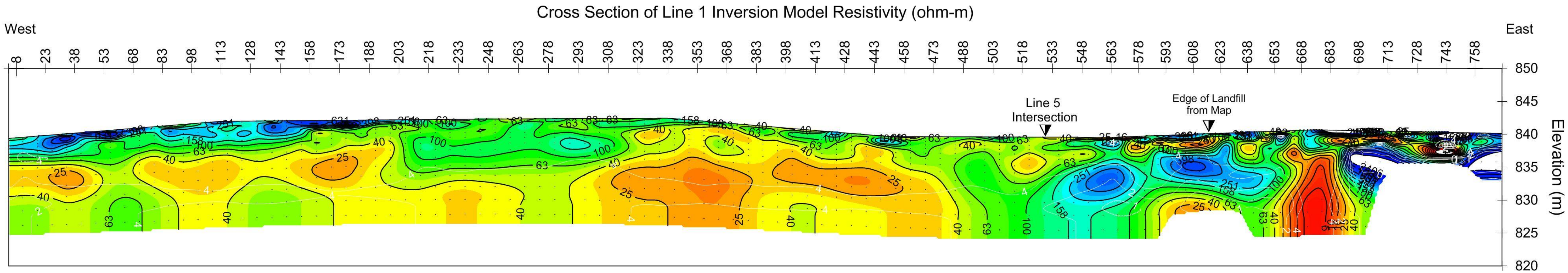


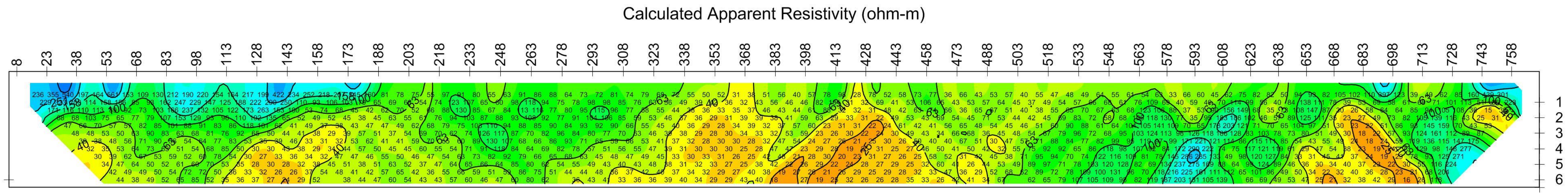
Survey Parameters:
Array: Dipole-dipole
a-spacing: 15 ft
Station spacing: 7.5 ft
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
Receiver: Zonge GDP32II
Transmitter: Zonge ZT-30
See report for additional survey details.

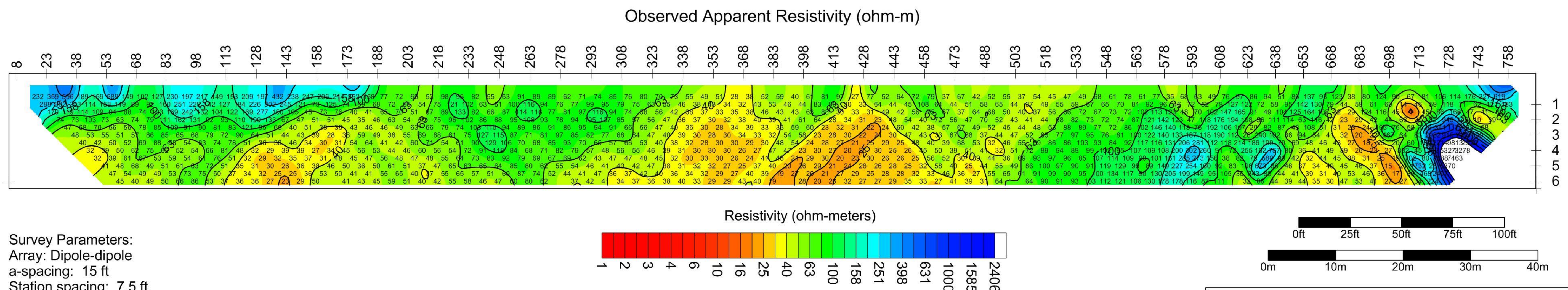
Inversion control parameters:
ResSmth=1, dpW=0.5, dxW=1, dzW=1
IPSmth=0.1, dpW=0.5, dxW=1, dzW=1
TS2DIP v4.60e
White contours show Sensitivity

Pima County Harrison Landfill
Line 1
for The City of Tucson
2D Smooth-Model Inversion
Dipole-Dipole Resistivity/IP Data

AUTHOR	DRAWN	DATE	SCALE	REPORT
Zonge	nrc	12/07/13	1:457	Job
REF:				







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a-spacing: 15 ft
Station spacing: 7.5 ft
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
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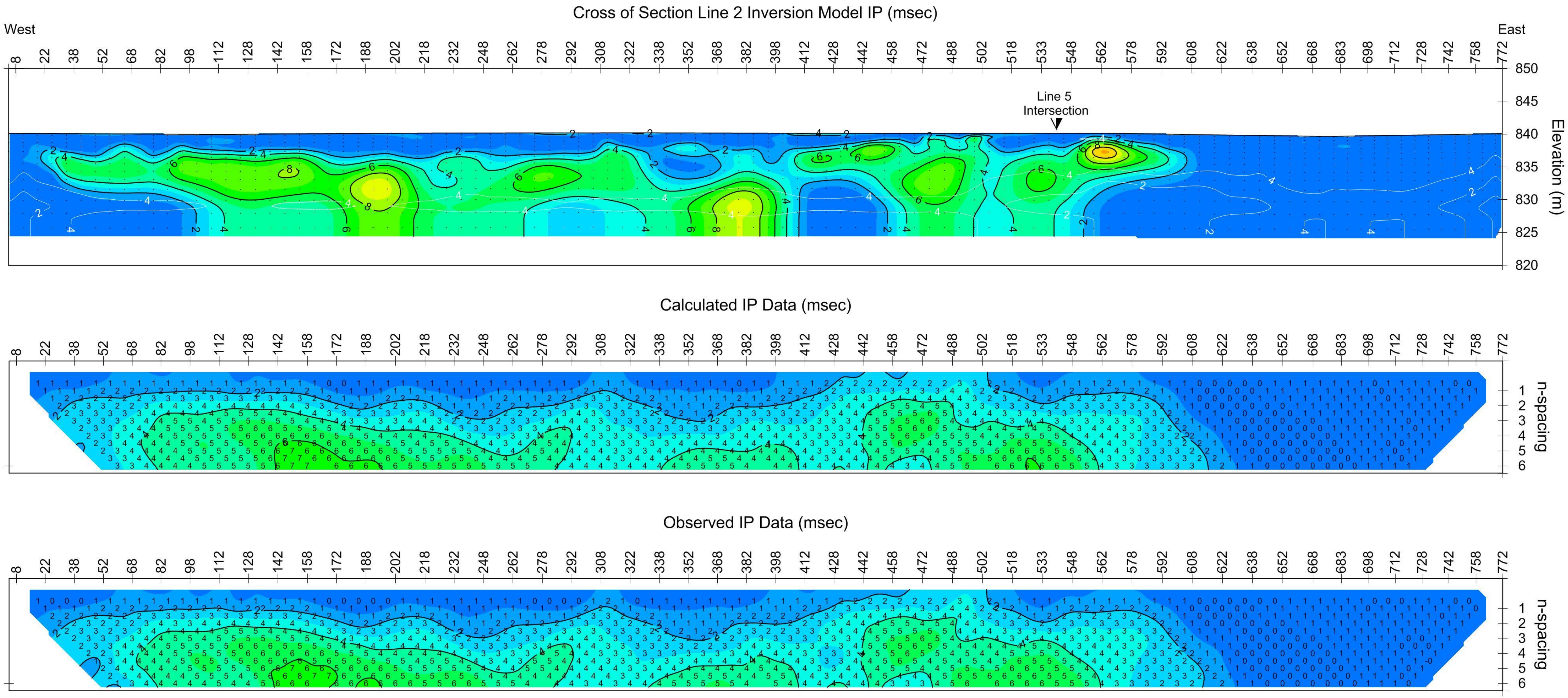
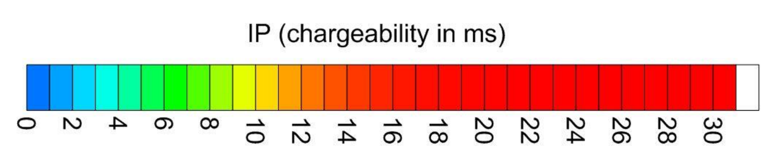
See report for additional survey details.

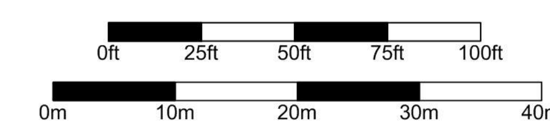
Inversion control parameters:
ResSmth=1, dpW=0.5, dxW=1, dzW=1
IPSmth=0.1, dpW=0.5, dxW=1, dzW=1
TS2DIP v4.60e
White contours show Sensitivity

Pima County Harrison Landfill
Line 1
for The City of Tucson
2D Smooth-Model Inversion
Dipole-Dipole Resistivity/IP Data

AUTHOR	DRAWN	DATE	SCALE	REPORT
Zonge	nrc	12/07/13	1:457	Job
REF:				







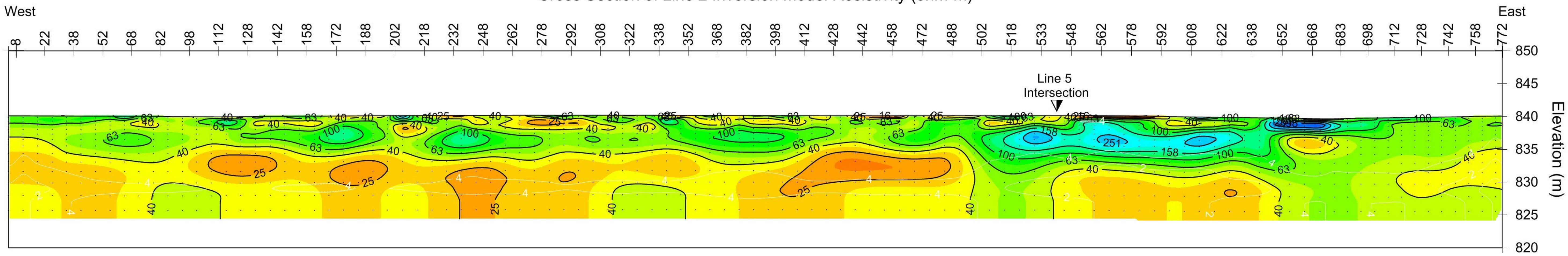
Survey Parameters:
Array: Dipole-dipole
a-spacing: 15 ft
Station spacing: 7.5 ft
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
Receiver: Zonge GDP32II
Transmitter: Zonge ZT-30
See report for additional survey details.

Inversion control parameters:
ResSmth=1, dpW=0.5, dxW=1, dzW=1
IPSmth=0.1, dpW=0.5, dxW=1, dzW=1
TS2DIP v4.60e
White contours show Sensitivity

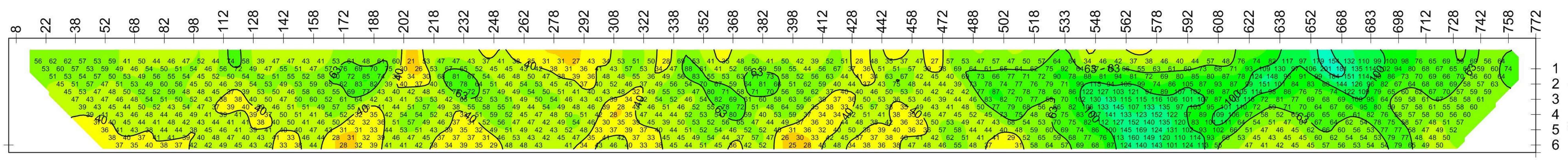
Pima County Harrison Landfill
Line 2
for The City of Tucson
2D Smooth-Model Inversion
Dipole-Dipole Resistivity/IP Data

AUTHOR	DRAWN	DATE	SCALE	REPORT
Zonge	nrc	12/07/13	1:457	Job
REF:				

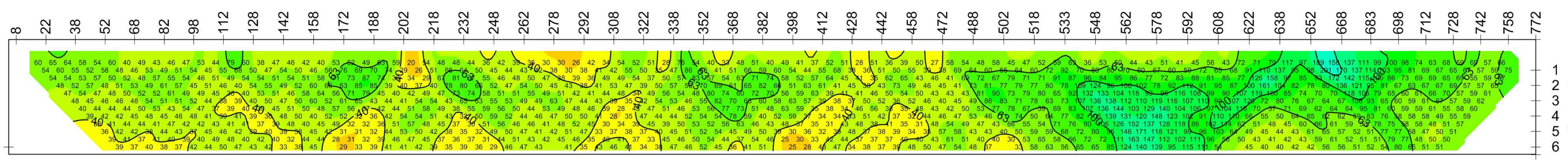
Cross Section of Line 2 Inversion Model Resistivity (ohm-m)



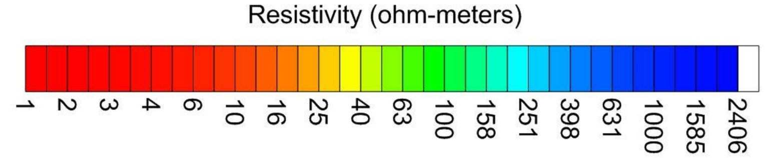
Calculated Apparent Resistivity (ohm-m)

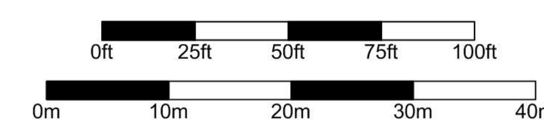


Observed Apparent Resistivity (ohm-m)



Resistivity (ohm-meters)





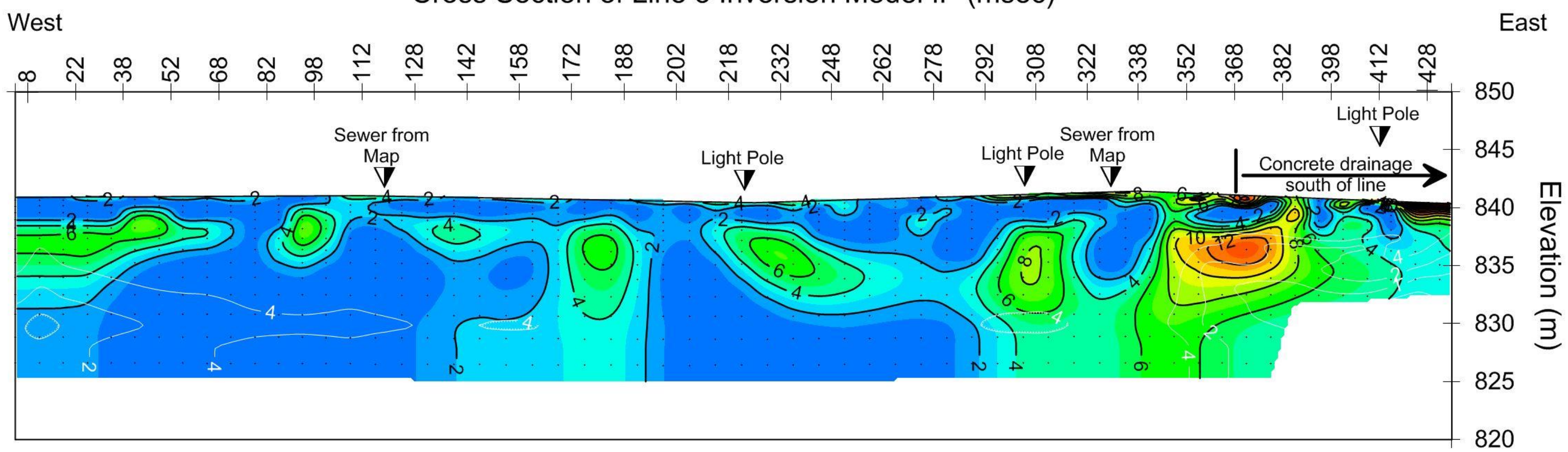
Survey Parameters:
Array: Dipole-dipole
a-spacing: 15 ft
Station spacing: 7.5 ft
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
Receiver: Zonge GDP32II
Transmitter: Zonge ZT-30
See report for additional survey details.

Inversion control parameters:
ResSmth=1, dpW=0.5, dxW=1, dzW=1
IPSmth=0.1, dpW=0.5, dxW=1, dzW=1
TS2DIP v4.60e
White contours show Sensitivity

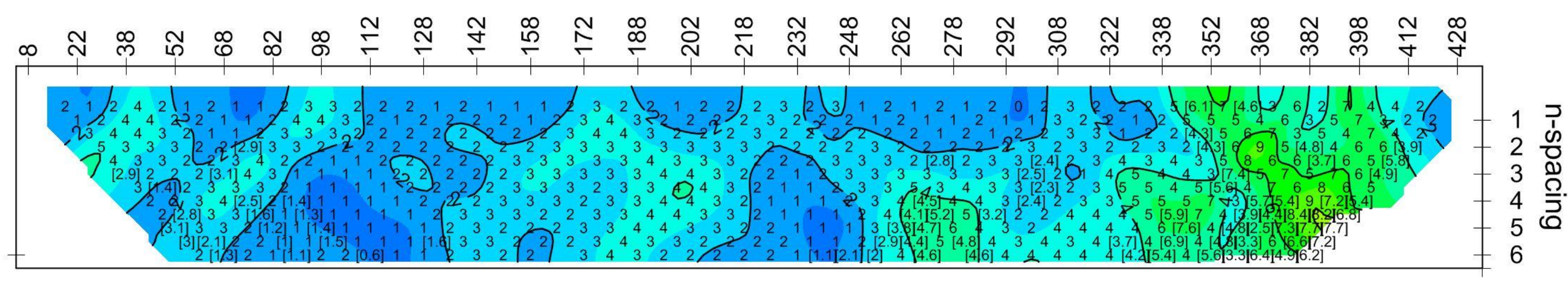
Pima County Harrison Landfill
Line 2
for The City of Tucson
2D Smooth-Model Inversion
Dipole-Dipole Resistivity/IP Data

AUTHOR	DRAWN	DATE	SCALE	REPORT
Zonge	nrc	12/07/13	1:457	Job
REF:				

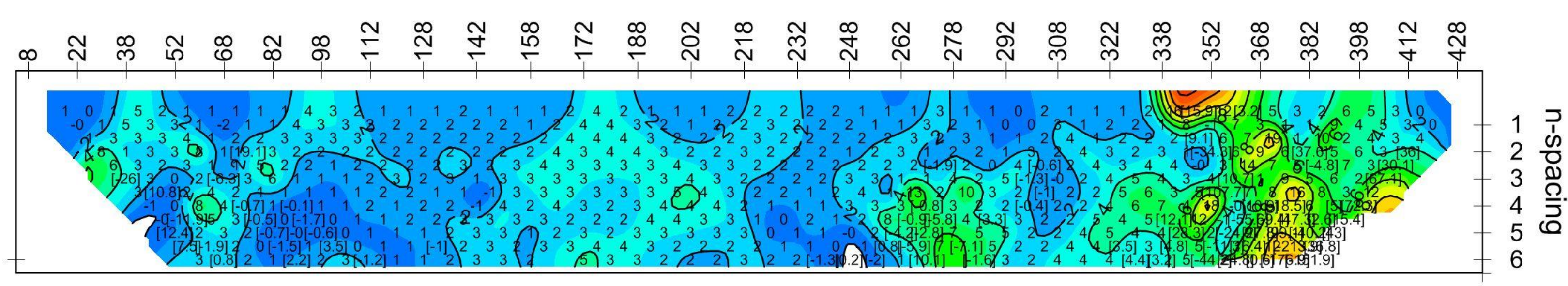
Cross Section of Line 3 Inversion Model IP (msec)



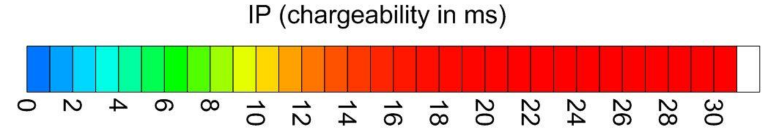
Calculated IP Data (msec)



Observed IP Data (msec)

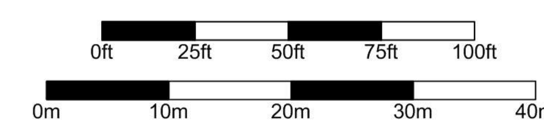


IP (chargeability in ms)



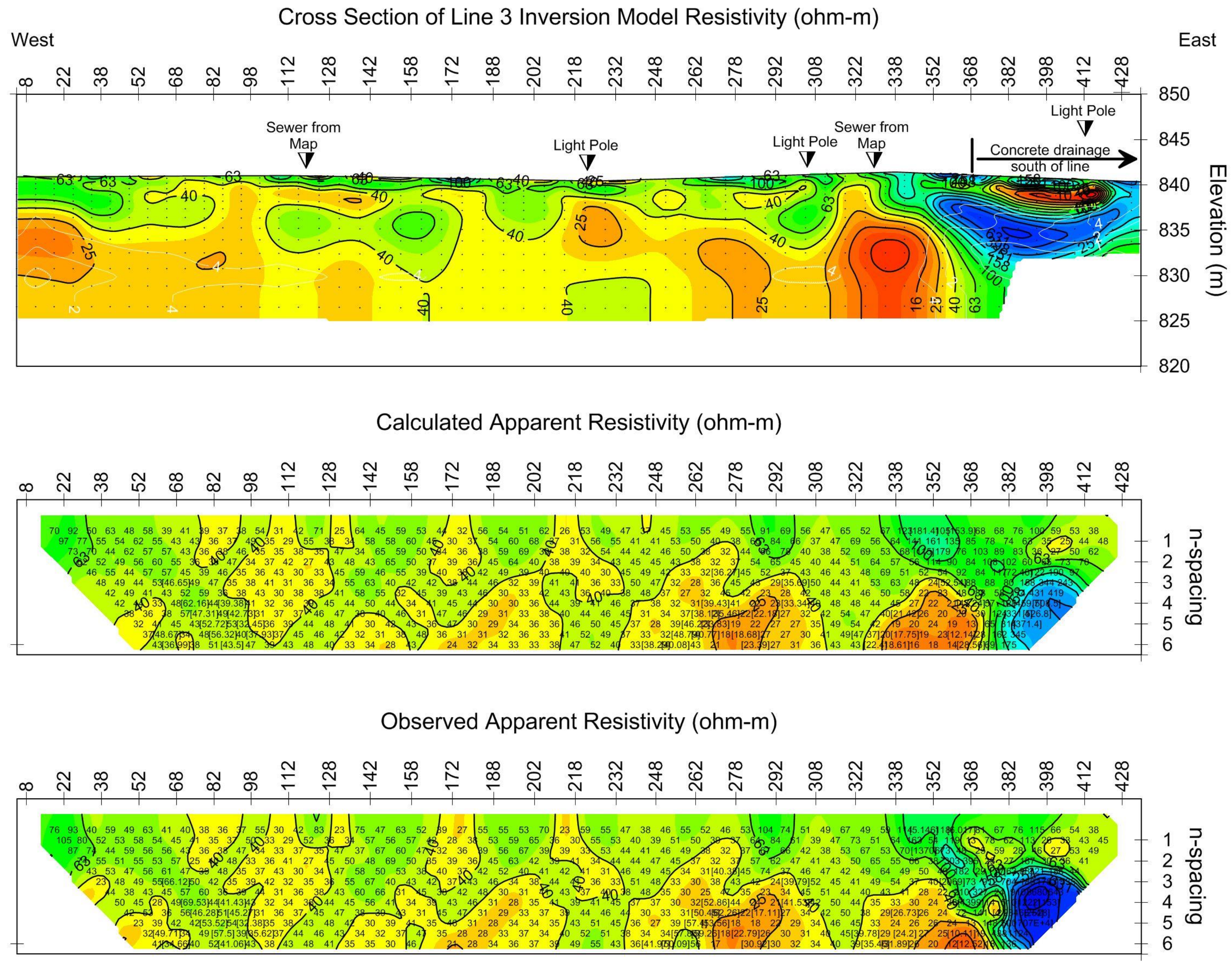
Survey Parameters:
Array: Dipole-dipole
a-spacing: 15 ft
Station spacing: 7.5 ft
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
Receiver: Zonge GDP32II
Transmitter: Zonge ZT-30
See report for additional survey details.

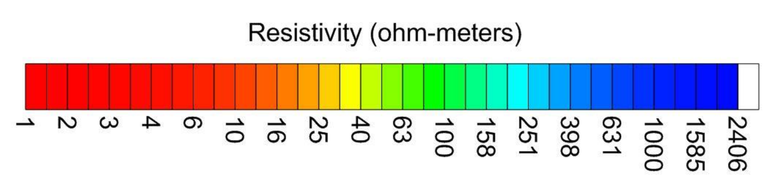
Inversion control parameters:
ResSmth=1, dpW=0.5, dxW=1, dzW=1
IPSmth=0.1, dpW=0.5, dxW=1, dzW=1
TS2DIP v4.60e
White contours show Sensitivity



Pima County Harrison Landfill
Line 3
for The City of Tucson
2D Smooth-Model Inversion
Dipole-Dipole Resistivity/IP Data

AUTHOR	DRAWN	DATE	SCALE	REPORT
Zonge	nrc	12/07/13	1:457	Job
REF:				





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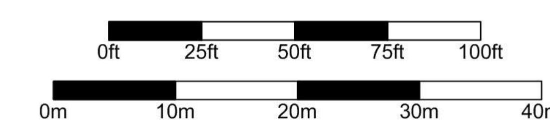
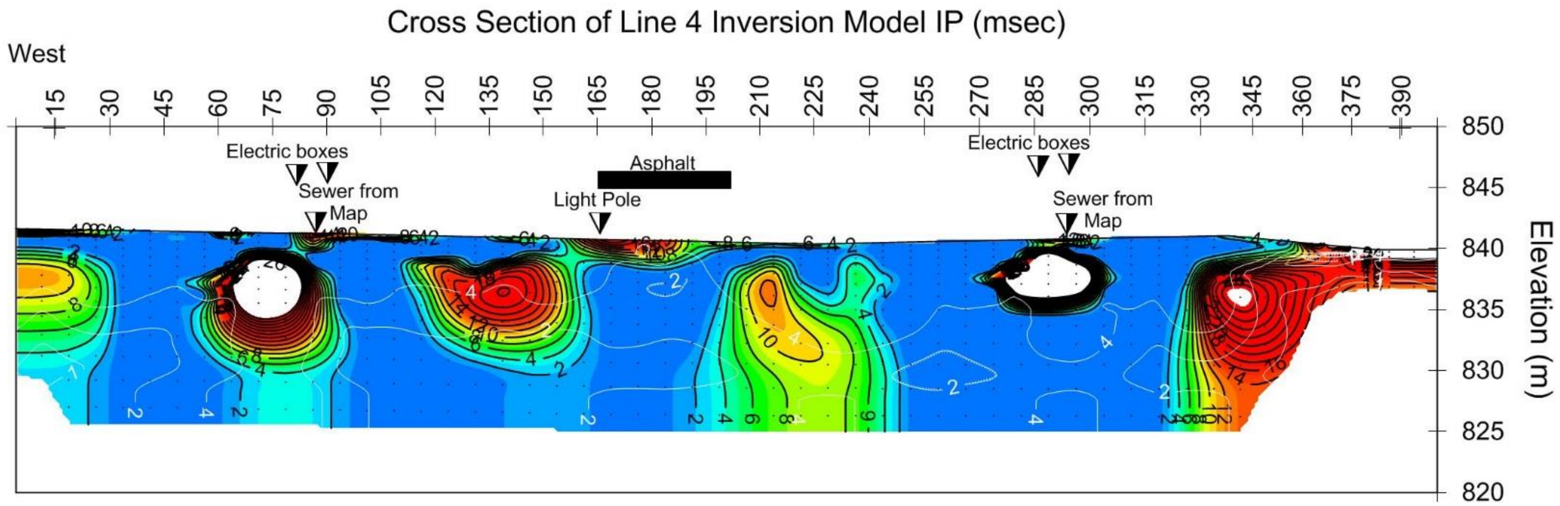
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
Receiver: Zonge GDP32II
Transmitter: Zonge ZT-30
See report for additional survey details.

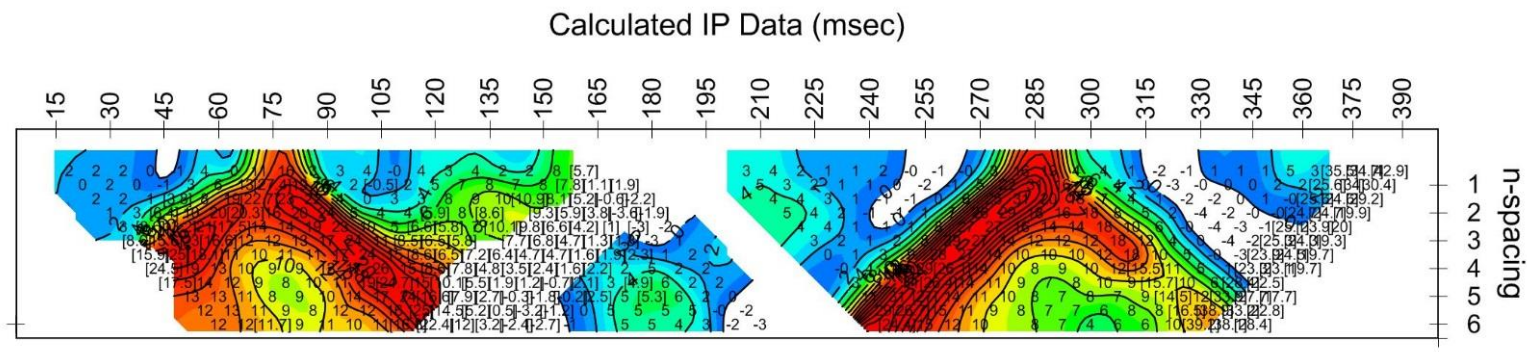
Inversion control parameters:
ResSmth=1, dpW=0.5, dxW=1, dzW=1
IPSmth=0.1, dpW=0.5, dxW=1, dzW=1
TS2DIP v4.60e
White contours show Sensitivity

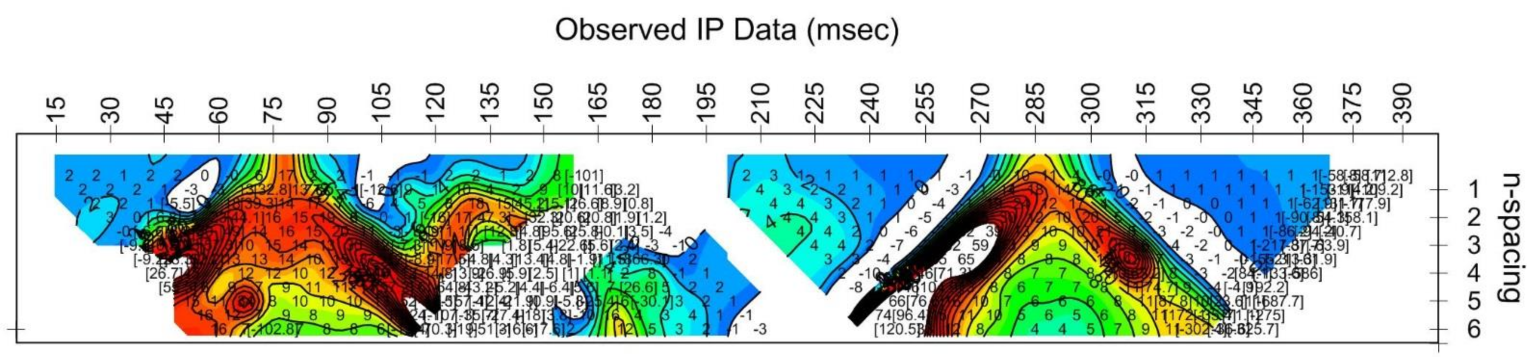


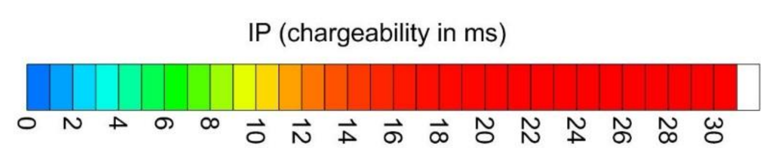
Pima County Harrison Landfill
Line 3
for The City of Tucson
2D Smooth-Model Inversion
Dipole-Dipole Resistivity/IP Data

AUTHOR	DRAWN	DATE	SCALE	REPORT
Zonge	nrc	12/07/13	1:457	Job
REF:				









Survey Parameters:
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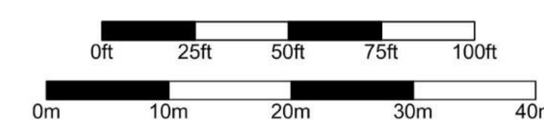
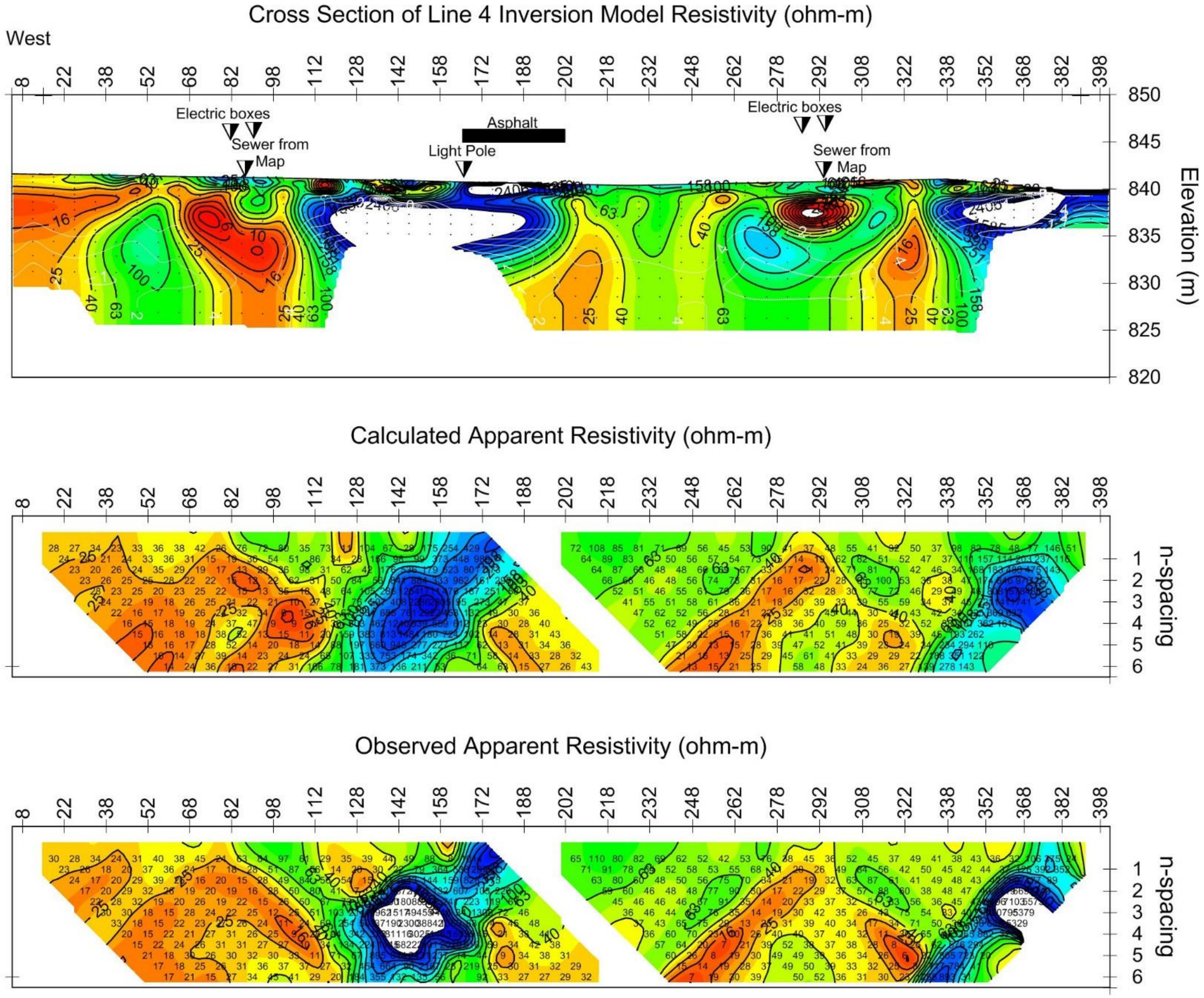
Station spacing: 7.5 ft
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
Receiver: Zonge GDP32II
Transmitter: Zonge ZT-30
See report for additional survey details.

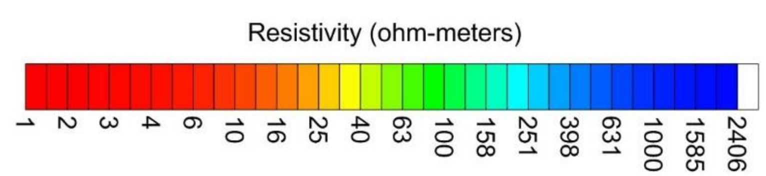
Inversion control parameters:
ResSmth=1, dpW=0.5, dxW=1, dzW=1
IPSmth=0.1, dpW=0.5, dxW=1, dzW=1
TS2DIP v4.60e
White contours show Sensitivity

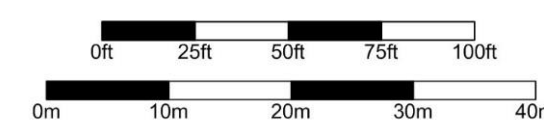


Pima County Harrison Landfill
Line 4
for The City of Tucson
2D Smooth-Model Inversion
Dipole-Dipole Resistivity/IP Data

AUTHOR	DRAWN	DATE	SCALE	REPORT
Zonge	nrc	12/07/13	1:457	Job
REF:				







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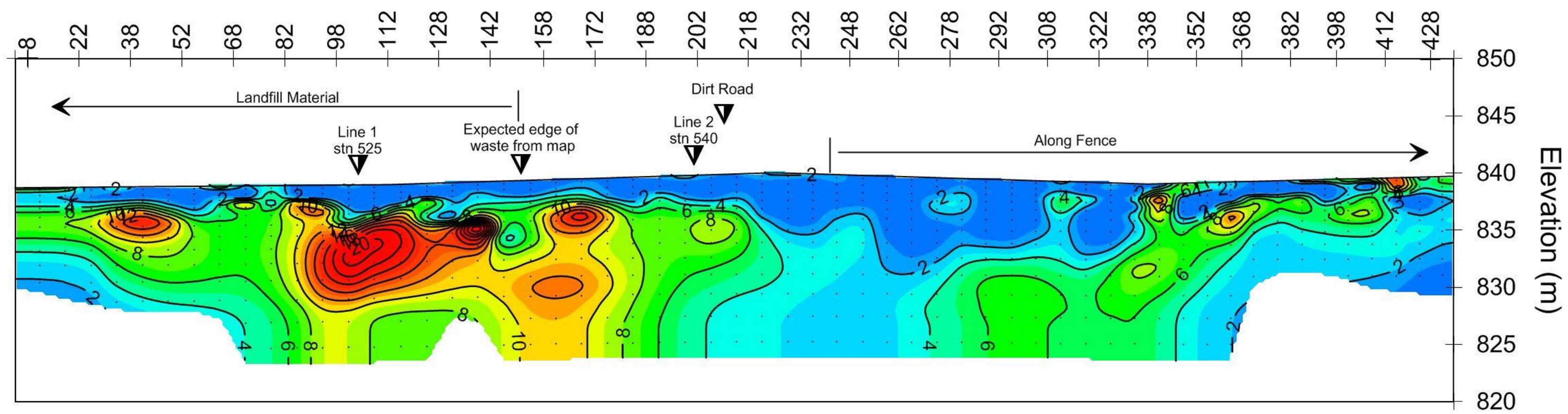
Station spacing: 7.5 ft
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
Receiver: Zonge GDP32II
Transmitter: Zonge ZT-30
See report for additional survey details.

Inversion control parameters:
ResSmth=1, dpW=0.5, dxW=1, dzW=1
IPSmth=0.1, dpW=0.5, dxW=1, dzW=1
TS2DIP v4.60e
White contours show Sensitivity

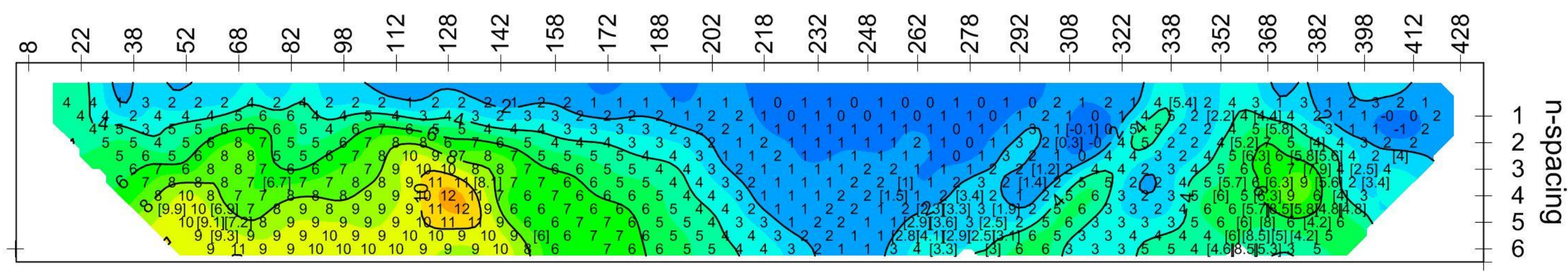
Pima County Harrison Landfill
Line 4
for The City of Tucson
2D Smooth-Model Inversion
Dipole-Dipole Resistivity/IP Data

AUTHOR	DRAWN	DATE	SCALE	REPORT
Zonge	nrc	12/07/13	1:457	Job
REF:				

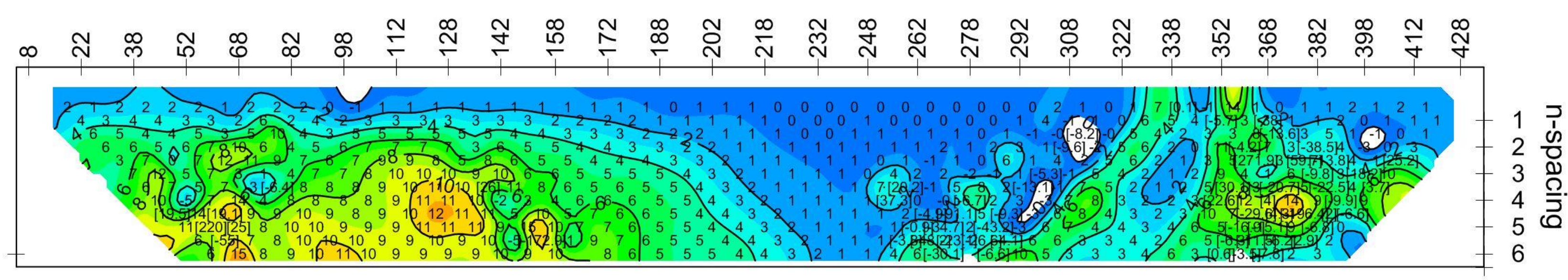
Cross Section of Line 5 Inversion Model IP (msec)



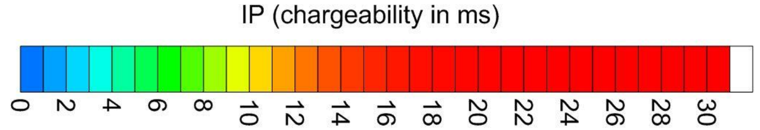
Calculated IP Data (msec)



Observed IP Data (msec)

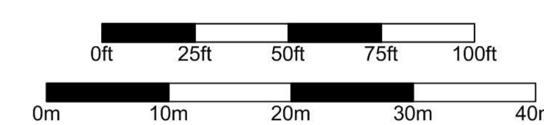


IP (chargeability in ms)



Survey Parameters:
Array: Dipole-dipole
a-spacing: 15 ft
Station spacing: 7.5 ft
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
Receiver: Zonge GDP32II
Transmitter: Zonge ZT-30
See report for additional survey details.

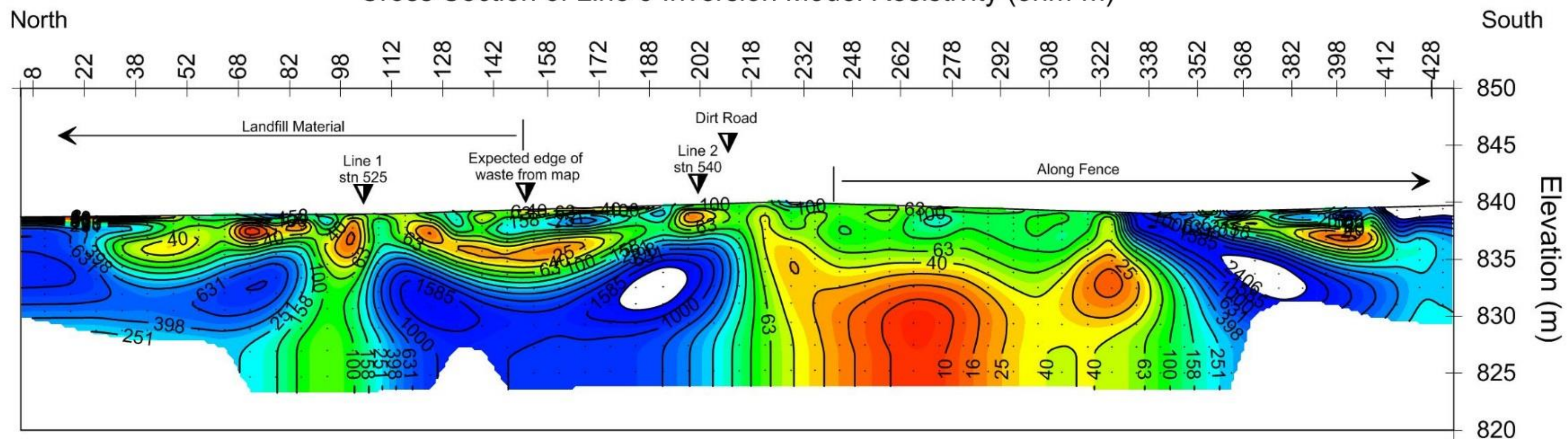
Inversion control parameters:
ResSmth=1, dpW=0.5, dxW=1, dzW=1
IPSmth=0.1, dpW=0.5, dxW=1, dzW=1
TS2DIP v4.60e
White contours show Sensitivity



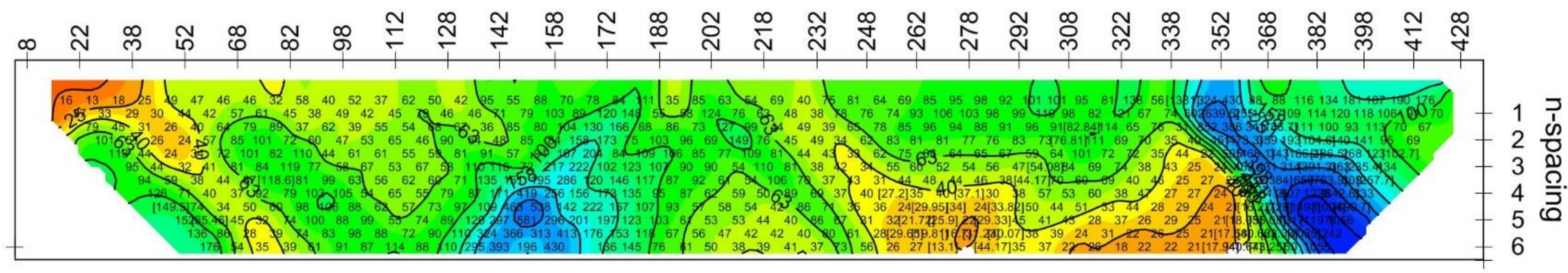
Pima County Harrison Landfill
Line 5
for The City of Tucson
2D Smooth-Model Inversion
Dipole-Dipole Resistivity/IP Data

AUTHOR	DRAWN	DATE	SCALE	REPORT
Zonge	nrc	12/07/13	1:457	Job
REF:				

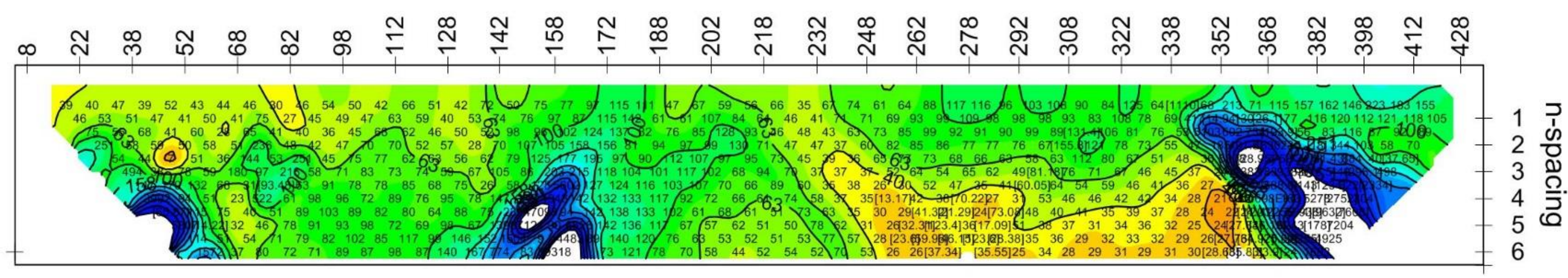
Cross Section of Line 5 Inversion Model Resistivity (ohm-m)



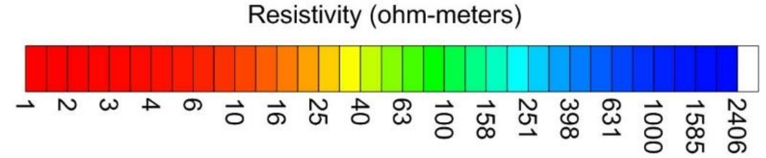
Calculated Apparent Resistivity (ohm-m)

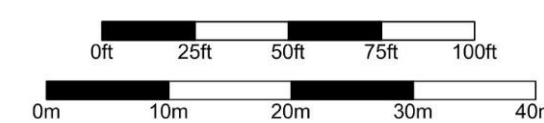


Observed Apparent Resistivity (ohm-m)



Resistivity (ohm-meters)





Survey Parameters:
Array: Dipole-dipole
a-spacing: 15 ft
Station spacing: 7.5 ft
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
Receiver: Zonge GDP32II
Transmitter: Zonge ZT-30
See report for additional survey details.

Inversion control parameters:
ResSmth=1, dpW=0.5, dxW=1, dzW=1
IPSmth=0.1, dpW=0.5, dxW=1, dzW=1
TS2DIP v4.60e
White contours show Sensitivity

Pima County Harrison Landfill
Line 5
for The City of Tucson
2D Smooth-Model Inversion
Dipole-Dipole Resistivity/IP Data

AUTHOR	DRAWN	DATE	SCALE	REPORT
Zonge	nrc	12/07/13	1:457	Job
REF:				

GEOPHYSICAL IP/RESISTIVITY SURVEY

Pima County Harrison Landfill

Tucson, Arizona

Appendix D

Noise Analysis Plots

for

The City of Tucson

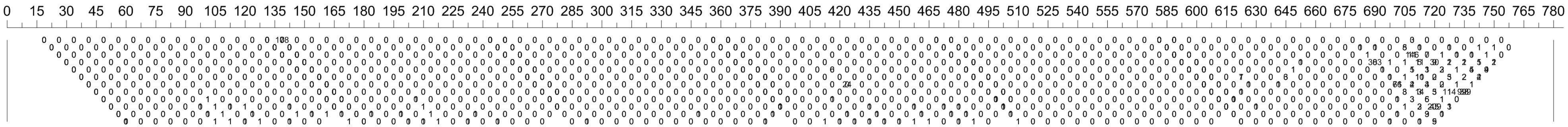
Environmental Services

ZONGE JOB# 13089

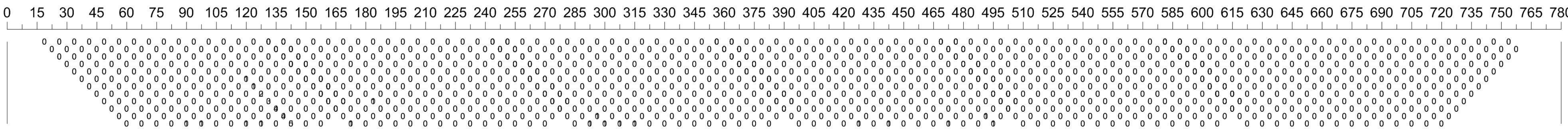
Issue Date: August 15, 2013

Zonge International, Inc.
3322 E. Fort Lowell Rd.
Tucson. Arizona, USA 85716
Zonge@zonge.com www.zonge.com

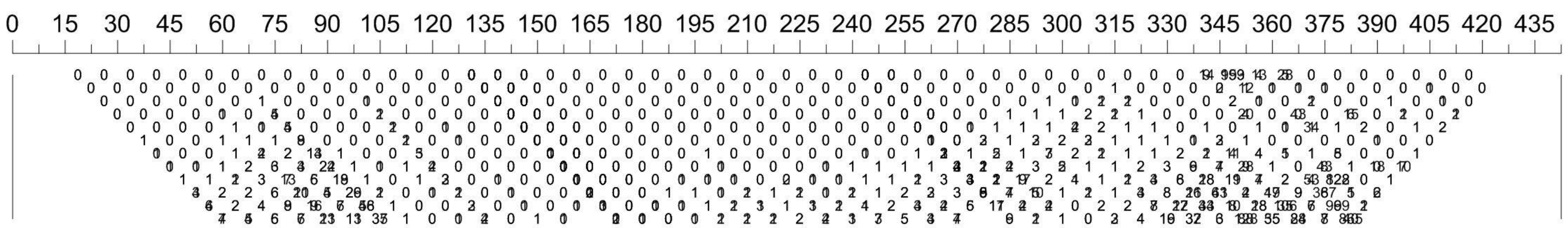
Line 1



Line 2

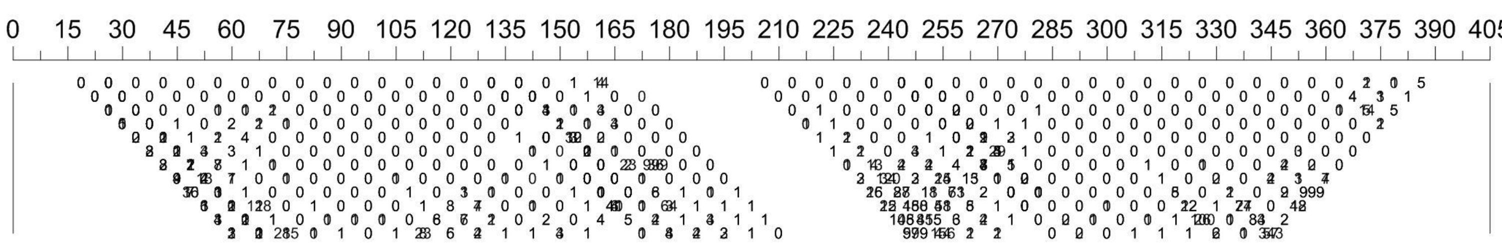


Line 3

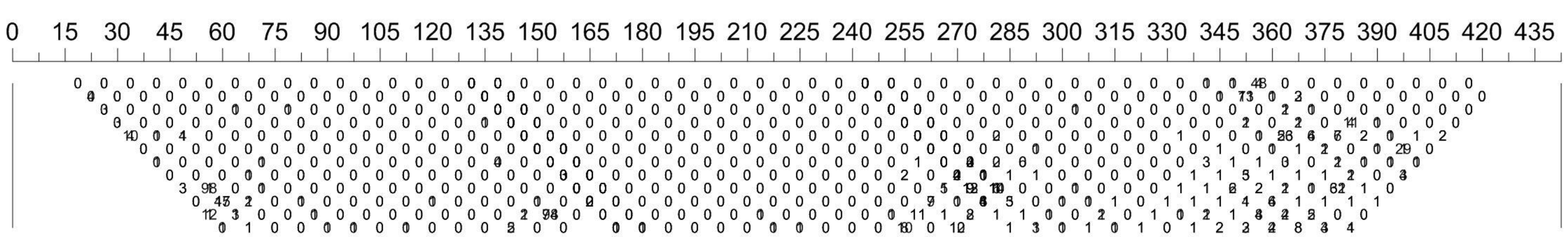


Array: Dipole-dipole
a-spacing: 15 ft
Station spacing: 7.5 ft
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
See report for additional survey details.

Line 4



Line 5



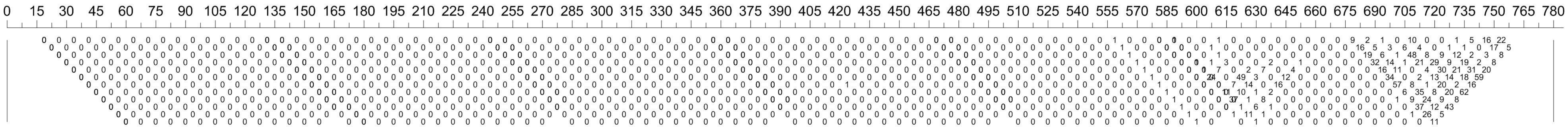
Appendix D
Pima County Harrison Landfill Project

Noise Analysis
IP (chargeability) Standard Error of the Mean
(milliseconds)

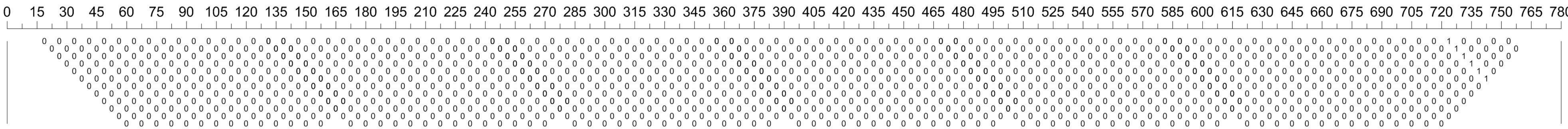
Dipole-Dipole Pseudosection Format

for
The City of Tucson- Environmental Services
by
Zonge International, Inc.

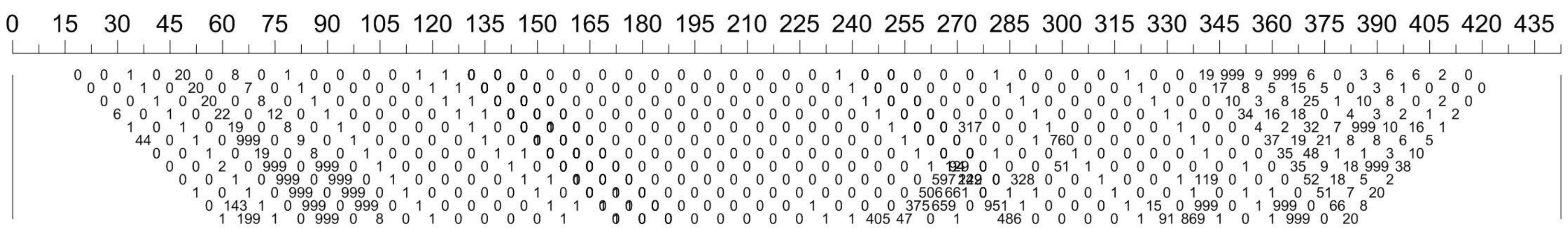
Line 1



Line 2

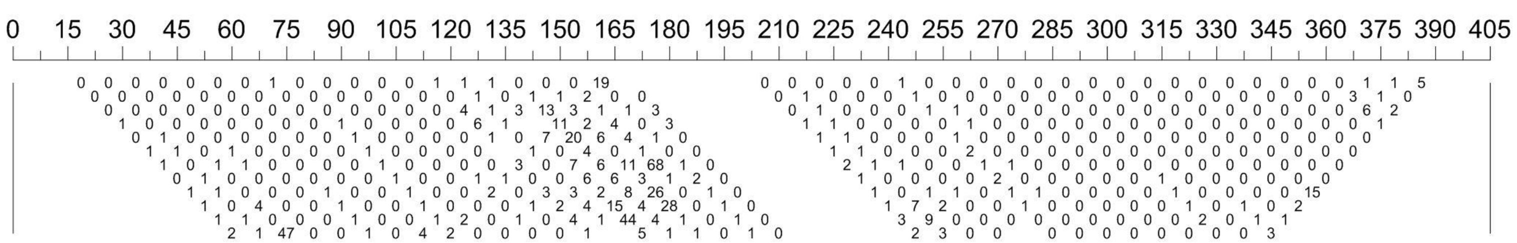


Line 3

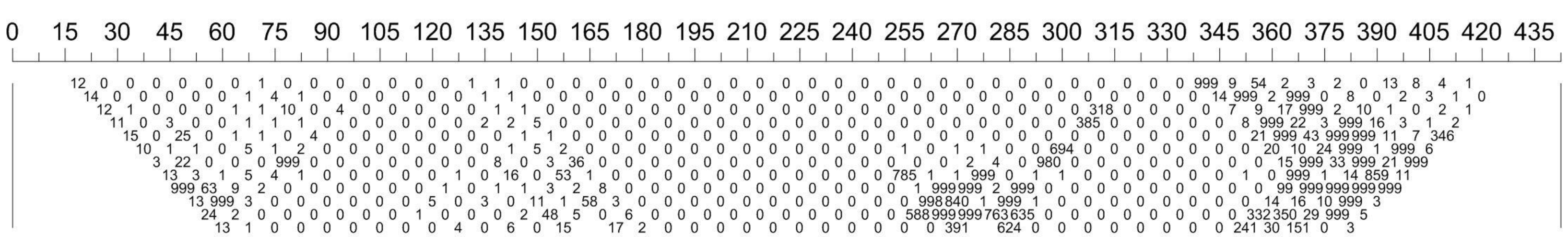


Array: Dipole-dipole
a-spacing: 15 ft
Station spacing: 7.5 ft
n-spacings: 0.5n through 6.0n in 0.5n increments
Stacks: 8 cycles, 0.5 Hz repetition rate, 50% duty cycle
Stacks per datapoint: 2+
Spread overlap: 2 diagonals (24 data points)
See report for additional survey details.

Line 4



Line 5



Appendix D
Pima County Harrison Landfill Project

Noise Analysis
% Error
Apparent Resistivity
(ohm-meters)

Dipole-Dipole Pseudosection Format

for
The City of Tucson- Environmental Services
by
Zonge International, Inc.